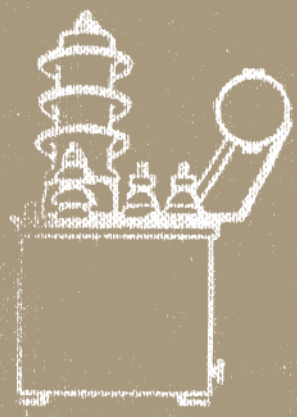
M. KIREYEV
A. KOVARSKY

SWITCHGEAR INSTALLATION



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МОНТАЖ И ЭКСПЛУАТАЦИЯ ЭЛЕКТРООБОРУДОВАНИЯ СТАНЦИЙ, ПОДСТАНЦИЙ И ЛИНИЙ ЭЛЕКТРОПЕРЕДАЧИ

«ВЫСШАЯ ШКОЛА» . МОСКВА

M. I. KIREYEV AND
A. I. KOVARSKY

SWITCHGEAR INSTALLATION

A Manual for Installers of Electrical Switchgear and Power Lines

Translated from the Russian
by
BORIS A. NIKOLAYEV

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The Russian Alphabet and Transliteration

А а	a	К к	k	Х х	kh
Б б	b	Л л	l	Ц ц	ts
В в	v	М м	m	Ч ч	ch
Г г	g	Н н	n	Ш ш	sh
Д д	d	О о	o	Щ щ	shch
Е е	e	П п	p	Ъ ъ	″
Ё ё	yo	Р р	r	Ы ы	y
Ж ж	zh	С с	s	Ь ь	′
З з	z	Т т	t	Э э	e
И и	i	У у	u	Ю ю	yu
Й й	y	Ф ф	f	Я я	ya

На английском языке

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Introduction

The electrical energy produced in power plants must be produced at the rate of utilization of the energy by the customers of the electric utility. There is no shortage of electrical energy in the system. This means that the load on all the generating equipment combined is constantly fluctuating. The utility can control the portion or amount of load each particular unit produces. Normally the most efficient plants operate at full or near full capacity. The less efficient plants are used to meet peak loads and are more likely to be operated at very light loads. In this way, the utility minimizes the operational cost of electric production.

Many problems are caused by the continual need to vary the output, to start up, close down, and maintain power plant equipment. Many elements in the power plant are critical. The choice of suitable switchgear depends to a larger extent on the actual duty than any other type of electrical equipment. In addition to switching on or off any section of an electrical installation, the switchgear generally includes the necessary protective devices which are desirable in order that the particular section may be automatically isolated if conditions become unsatisfactory. When the system malfunctions in any way, e.g. a short-circuit to earth on a line or transformer, rapid automatic means are required to remove the faulty equipment. At the same time the remainder of the system must be left operating intact. System protection embraces the various measuring and relaying schemes used to achieve this aim. In a large highly interconnected supply network efficient protection is of the utmost importance, and its malfunction can bring about a wholesale electrical collapse of the supply system. Protection is intimately

connected with switchgear, the former representing the 'nervous system' and the latter the resulting physical action.

The switches by means of which the system is controlled are known as circuit breakers. At high voltages these may have several breaks (contacts) per phase and are very large and complicated structures. The very act of opening a circuit, which at domestic voltages is taken for granted, at very high voltages becomes a major engineering problem.

The book is intended as a manual for use in vocational schools and by workers being trained on-the-job. It may also be useful to installers and operators who want to improve their proficiency. The book has been written on the basis of the experience in the installation, operation, and maintenance of electrical equipment accumulated by a number of Soviet erection agencies, design institutes, electric power stations, and power systems.

The material presented in the book complies with the codes and regulations currently in effect in the USSR, these including the Electric Installation Code, Building Code, Operating Rules, and Safety Regulations for Electrical Installations, i.e. for installations in which electric energy is produced, transformed, distributed, and used.

In any country the development of power industry requires numerous installers and electricians trained in the operation and maintenance of station, substation, and line equipment and, consequently, there is a great demand for books on power engineering. The authors hope that this book will aid in training skilled electricians.

PART ONE ● INSTALLATION
OF POWER SYSTEM EQUIPMENT

CHAPTER 1

Electric Power Generation and Distribution

1. Electric Power Supply

Electric power is produced by electric generators installed at electric power stations and driven by prime movers. If the prime mover is a steam turbine, the station is called thermal. Also grouped with thermal power stations are nuclear power plants. The station employing a hydraulic turbine as the prime mover is known as hydroelectric.

Power from electric power stations is delivered to the loads via switchgear (РУ) and substations as illustrated in Fig. 1.

2. Types of Station and Substation Switchgear

Switchgear installations may be subdivided into:

(1) indoor switchgear installations (ЗРУ), in which the equipment is placed within a building;

(2) outdoor switchgear installations (ОРУ), in which the equipment is mounted in the open air.

Indoor switchgear is most often designed for voltages up to and including 10 kV. But in the neighbourhood of chemical plants and in coastal areas, where the ambient atmosphere contains substances detrimental to insulation and metal parts, indoor switchgear rated for higher voltages is installed.

Outdoor switchgear installations are generally designed for service at 35 kV upwards. Outdoor switchgear rated for 6 10 kV is also used.

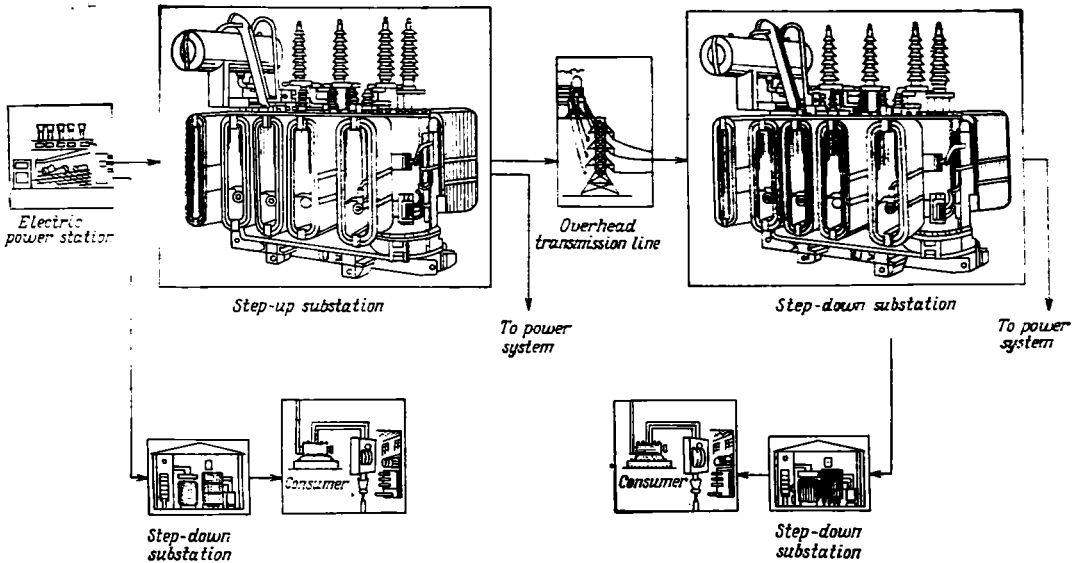


Fig. 1. Power transmission and distribution

Formerly, most indoor switchgear installations were cubicle type, with the equipment assembled at the site. At the present time, factory-assembled metal-clad switchgear (the KPУ type) is most generally employed. This most advanced equipment manufactured by industrial methods at factories comes as fully equipped and wired units.

A modern factory-assembled metal-clad switchgear unit is shown in Fig. 2. As seen from the figure, the unit is partitioned into compartments. Compartment *1* accommodates roll-out truck *18* mounting switch *15* with operating mechanism *16*. Arranged in compartment *2* are cable assembly *4*, current transformers *3*, protective earthing transformers, and earthing switch *19*. The same compartment also houses primary break contact *6*. Compartment *10* is intended for collecting busos *9* secured to support insulators *8*. Installed between compartments *5* and *10* is bushing insulator *7*. Compartment *13* contains protective gear *11* and swivel frame *12* to mount a meter.

The truck is moved by a mechanism operated by means of rod *17* provided with a handle. Once the truck is rolled out of the unit, lower primary fixed contacts are grounded by earthing switch *19*. There is a peep-hole in the front of the truck. Connector *14* connects the secondary circuits of the truck to the protective gear.

The truck can take three positions. One of these is the operating position, where the truck is completely pushed into the unit, and primary break contacts *6* connected to their fixed counterparts. In the second position, the truck is pulled out of the unit, but the secondary circuits are still energized via a flexible hose and connector *14*. The secondary circuits can be tested and checked as needed in this position. In the third position, the truck is completely pulled out of the unit so that repairs to the equipment mounted on the truck can be carried out.

Use is also made of factory-assembled metal-clad outdoor switchgear units (the KPУH type). They are similar in design to KPУ units, yet suited for installation in the open air (as indicated by the letter H in their designation).

Substations comprising factory-assembled metal-clad outdoor switchgear are also available as factory-preassembled sets.

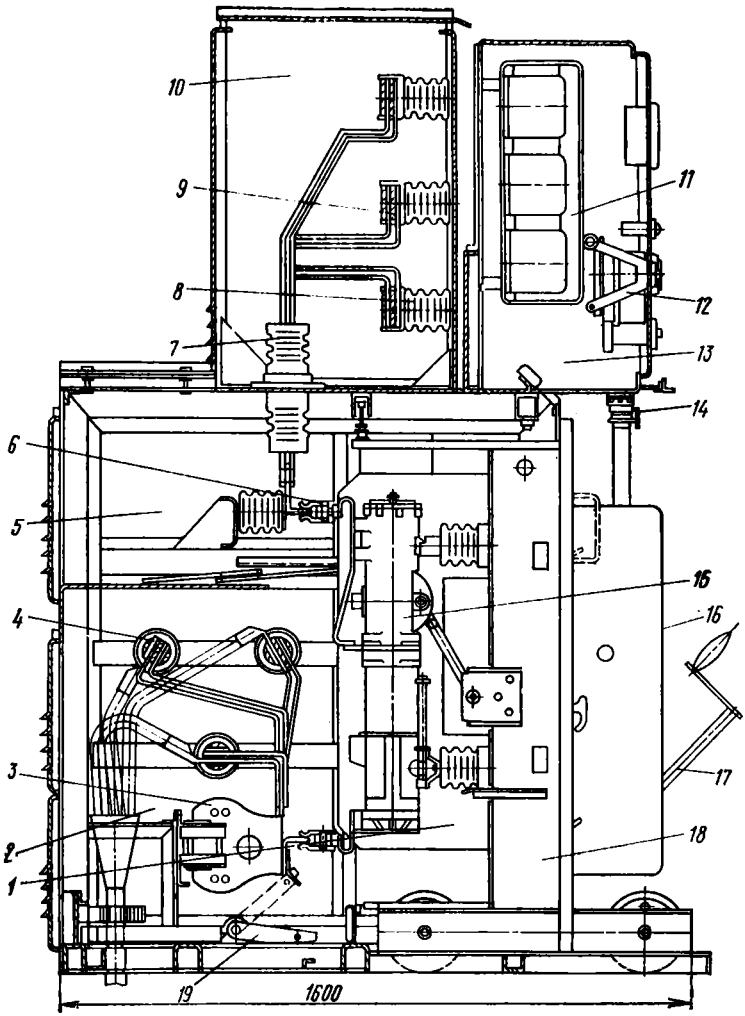


Fig. 2. КРУ unit with ВМП-10К oil circuit breaker and ПЭ-11 operating mechanism

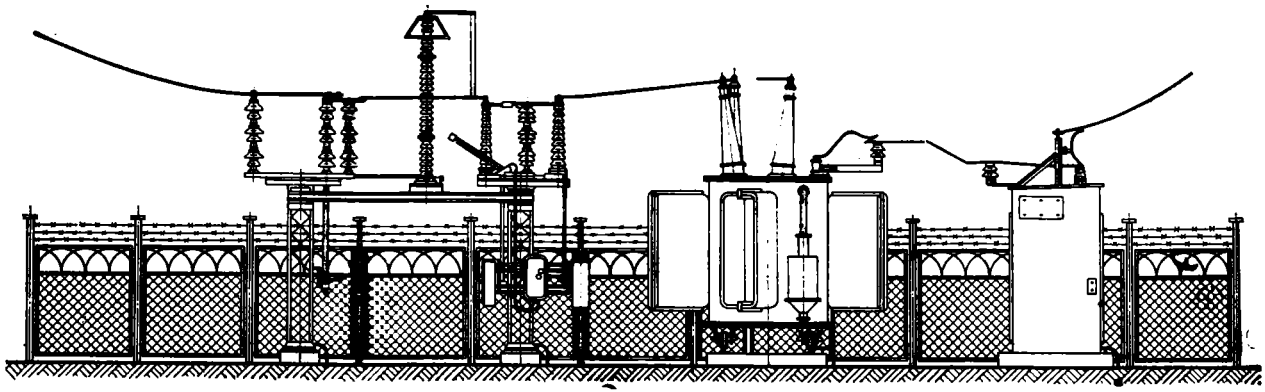


Fig. 3. КТП-110 factory-preassembled transformer substation

Equipment of the КРУ, КРУН, and КТП (factory-pre-assembled transformer substations — Fig. 3) types reduces in-situ wiring-up and capital outlay, improves workmanship and cuts down erection time.

3. Main Connections and Diagrams. Elements of Switchgear Design

Modern power stations and substations may have differently arranged switching connections. Some of the simplest schemes are shown in Fig. 4.

The scheme depicted in Fig. 4*a* features an isolator (disconnecting switch) and fuses.

In the scheme presented in Fig. 4*b*, used instead of the isolator is a load-breaking isolator which enables one not

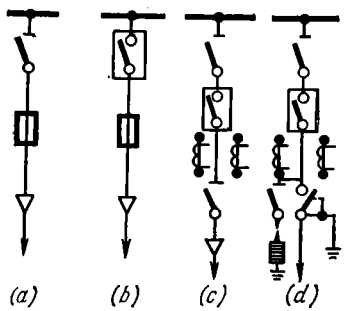


Fig. 4. Some of the simplest connections to main buses of substation (*a*) with isolator and fuses; (*b*) with load-breaking isolator; (*c*) with switch, bus and line isolators; (*d*) with isolator having earthing blades and arresters

only to de-energize an electric load but also to perform the required switchings-off under load.

Figure 4*c* illustrates a scheme comprising a power switch, instrument current transformers, and two isolators. The power switch is designed to carry out various switchings, including those performed under load. The current transformers feed power to the windings of measuring instruments and relays, and the function of the isolators is to de-energize specific portions of the circuit. The isolators may be operated only after the switch has been opened.

The connection shown in Fig. 4*d*, is the same as in Fig. 4*c*. But the lower (line) isolator has earthing blades. Again, arresters are added to the scheme to protect the installation from overvoltage.

Figure 5 depicts the connection of a low-capacity power transformer operating at 6-kV primary voltage and

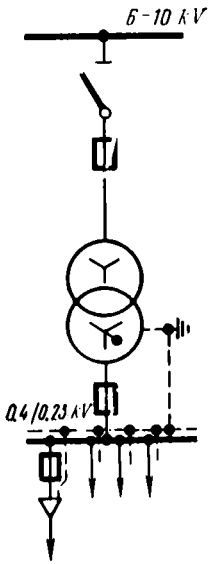


Fig. 5. Connection of power transformer rated under 400 kVA

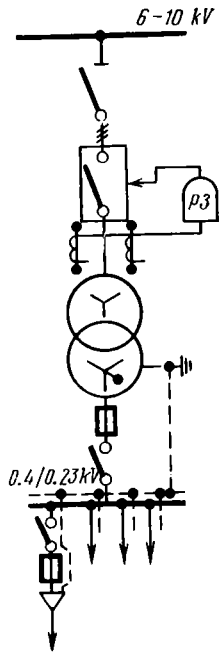


Fig. 6. Connection of power transformer rated above 400 kVA

0.4/0.23-kV secondary voltage. The transformer is de-energized by a bus isolator, which must be done only at no-load. The transformer is protected by fuses on both the high-voltage and the low-voltage sides.

The connection of a higher-capacity power transformer is shown in Fig. 6. The scheme comprises a switch designed to perform switching operations and protective relays (P3), drawing current from instrument current transformers.

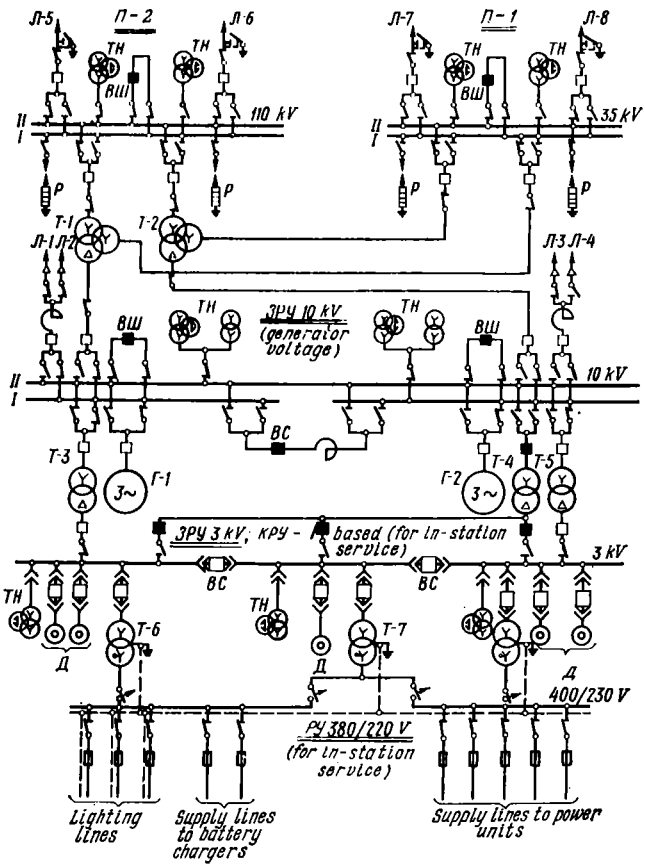


Fig. 7. Primary power connections at thermal power station. Single-line diagram

ЗРУ-indoor switchgear installation; РУ—switchgear installation; Л-1, Л-2, Л-3, Л-4, Л-5, Л-6, Л-7, Л-8—supply lines to consumers; П-1, П-2—substations; ТН—voltage transformer; Т-1, Т-2, Т-3, Т-4, Т-5, Т-6, Т-7—transformers; ВШ—busbar coupler; ВС—bus-sectionalising switch; Р—arrester; Г-1, Г-2—generators; Д—arc control device

Presented in Fig. 7 is a single-line schematic diagram of primary power connections at a thermal power station. The 10-kV main indoor substation (ЗРУ) employs a double-bus system having one of its buses sectionalized, i.e. divided

into two sections by a bus-sectionalizing circuit breaker (ВС). With the double-bus system incorporating the two sections of one bus and busbar couplers (ВШ), the continuity of power supply and the capacity for switching operations are raised to a maximum (see Ch. 11). The nearest consumers

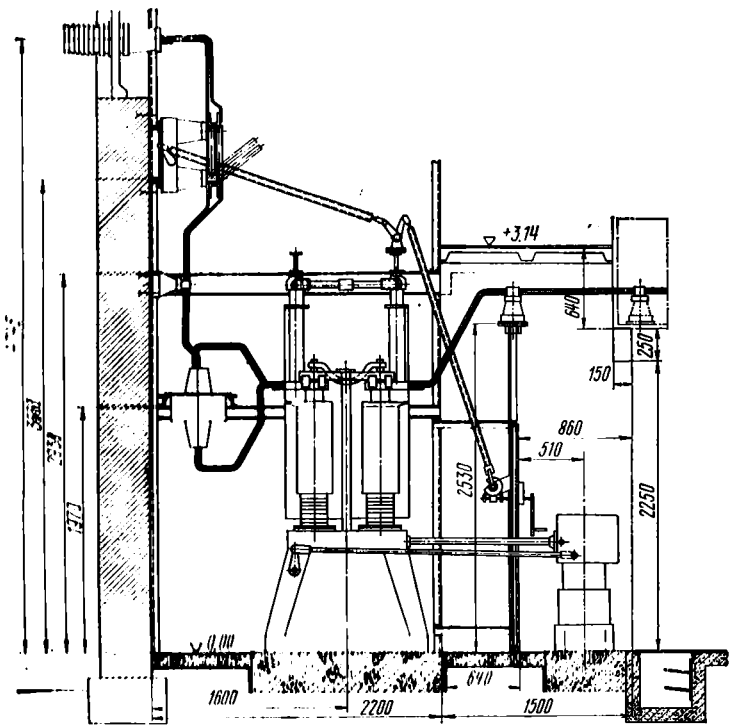


Fig. 8. Power-switch cell. Installation drawing

are directly supplied with power by the 10-kV main indoor substation via lines Л-1, Л-2, Л-3, and Л-4. The distant consumers are supplied with power via outdoor switchgear units of substations П-1 and П-2 operating at 35 kV and 110 kV, respectively. The station loads are powered by a 3-kV indoor switchgear installation made up of КРУ units.

The outline of a switchgear structure and the arrangement of the equipment and current-carrying parts in the switchgear rooms are shown in a layout diagram. Though they are not drawn to scale and do not represent the dimensions of

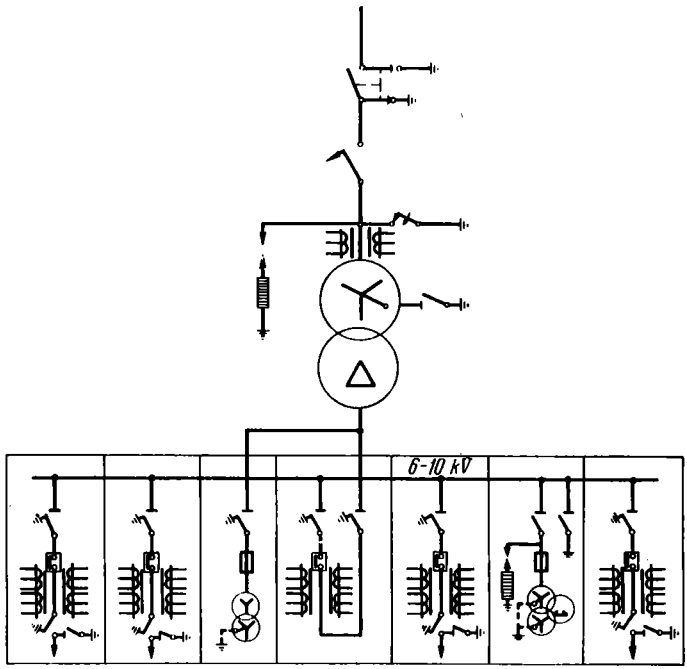


Fig. 9. Primary power connections at КТП-110/6-10-kV outdoor substation

the structure, layout diagrams give a clearer idea of the arrangement of equipment in switchgear structures. They are also useful when drawing bills of the electrical equipment needed for a particular installation.

The drawings to which electrical equipment is installed are drawn to scale (Fig. 8).

Schematic diagrams, layout diagrams, and installation drawings are parts of a design.

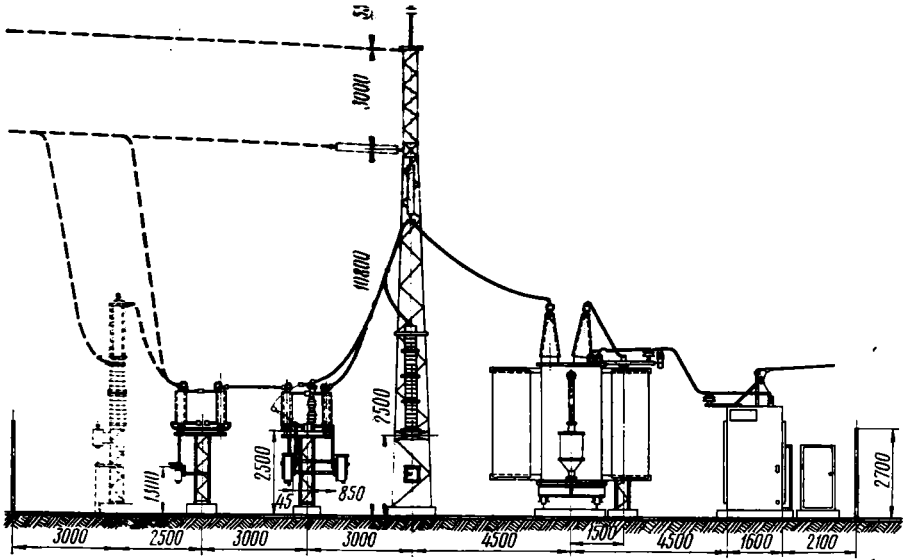


Fig. 10. КТП-110/6-10-kV outdoor substation. Longitudinal section

Figures 9 and 10 present some of the graphic components of the design of an outdoor switchgear installation employing a KTP-110/6-10-kV factory-preassembled transformer substation.

Questions and Exercises

1. What do the Russian designations РУ, ЗРУ, ОРУ, КРУ, КРУН, КТП, КТПП stand for?
2. Diagram the connection of a line to the buses of a substation; use a load-breaking isolator and fuses.
3. Diagram the connection of a line to the buses of a substation; use a power switch, bus and line isolators, and current transformers.
4. Given the single-line schematic diagram of a switchgear system, explain the arrangement of the associated thermal power station.

CHAPTER 2

Installation of 6-10-kV Indoor Primary Circuit Equipment

4. Mounting of Support (Post) Insulators

Design and types. An indoor support insulator (Fig. 11*a*) is provided with threaded sockets in the cap to attach busbar structures and with through holes in the base fitting to secure the insulator. Bolt *4* serves to earth the insulator base fitting. Support insulators may have round, oval, or square base fittings.

Also available are small-size insulators (the OMA type) (Fig. 11*b*), their caps and base fittings being substituted by

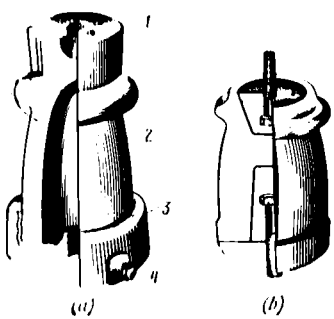


Fig. 11. Indoor-type support (post) insulators
(*a*) OD-10-375кр; (*b*) OMA-10; *1*—cap; *2*—porcelain body; *3*—base fitting; *4*—bolt

steel parts cemented in a porcelain body, which makes the insulator much lower.

The types and mounting dimensions of support insulators are presented in Table 1 and Fig. 12.

Inspection. Support insulators must comply with the following requirements:

Table 1

Types and Mounting Dimensions of Support Insulators

Type designation	Fig. 12	Dimensions, mm		
		H	*D*	*d**
ОФ-6-375 кр	*a*	165	108	M12
ОФ-6-375 ов	*b*	165	135	2×12
ОФ-10-375 кр	*a*	190	108	M12
ОФ-10-375 ов	*b*	190	135	2×12
ОФ-6-750 кр	*a*	185	132	M16
ОФ-6-750 ов	*b*	185	175	2×15
ОФ-10-750 кр	*a*	215	132	M16
ОФ-10-750 ов	*b*	215	175	2×15
ОФ-10-750 кв	*c*	215	150	4×15
ОФ-10-1250 кв	*c*	225	140	4×16
ОФ-10-2000 кв	*c*	235	155	4×16

* *d* — diameter of bolt hole

Note. The following designations are used: О — support (insulator), Ф — porcelain (insulator); 6, 10 — voltage rating, kV; 375, 750, 1250; 2000 — bending load at collapse, kg; кр, ов, кв — round, oval, square base fitting, respectively.

the porcelain must have no chipped spots, metallic inclusions, unglazed spots, or haircracks in the glazing; the latter can be detected using a magnifying glass or by wetting the insulator with kerosene which will seep into cracks, if any, and thus make them visible as dark lines;

the cap and base fittings should be securely cemented on;

the tolerance on lack of parallelism between the cap and the base-fitting plane is 1 mm; this tolerance also applies to the offset of the cap or base fitting from the centre line of the insulator;

insulators should not differ in height by more than ±2mm. Insulators having the same deviation should be used within one cell or on one section of busbars.

Mounting. Insulators are bolted to the metalwork of cubicle-type and factory-assembled switchgear structures (Fig. 13). For reliable electric contact, the bottom surface of

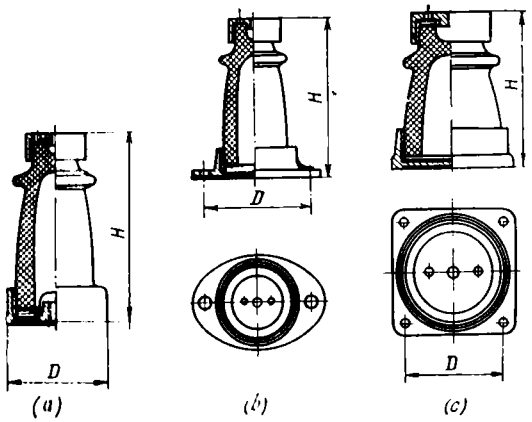


Fig. 12. Dimensions of different support insulator types
(a) with round base fitting; (b) with oval base fitting; (c) with square base fitting

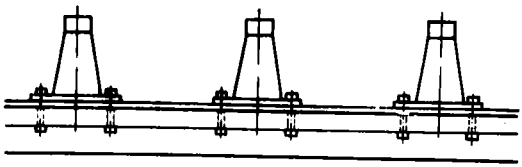


Fig. 13. Support insulators bolted to metalwork

the insulator base fittings and the mounting seats on the metalwork are cleaned until bright and coated with petroleum jelly or cup grease. The metalwork is connected to earth to provide for the safety of attending personnel.

When complementing and rearranging switchgear structures the equipment of which has been installed directly on brickwork or concrete, insulators may be secured with anchor studs or through bolts, with earth-continuity conductors connected to the bolts provided on the insulator base fittings.

Of insulators intended to support collecting buses, the outermost insulators are first installed at both sides, then a string or thin flexible cable is strung between them, and next

the intermediate insulators are set up to line with the outermost ones.

Irrespective of the installation technique, the axes of the caps or base fittings of the insulators of any one phase should be within ±5 mm of the same line. This tolerance also applies to the three insulators in any one group.

The caps of the insulators in any one group, and also in one cell or on a given bus section should be within ±2 mm of the same level. Their alignment is checked with a spirit level and a straight edge. Misalignment is removed by inserting steel shims under the insulator base fittings, or by slipping C-type steel washers on the fastening bolts. The shims or washers should not extend beyond the base fittings.

The centre distance between the phases and the distance of the outer-phase centre line to a structural surface or earthed member must be within ±5 mm of the dimension given in the working drawing.

5. Mounting of Bushings

Design and types. Bushings serve to carry live parts through walls and floors in switchgear structures.

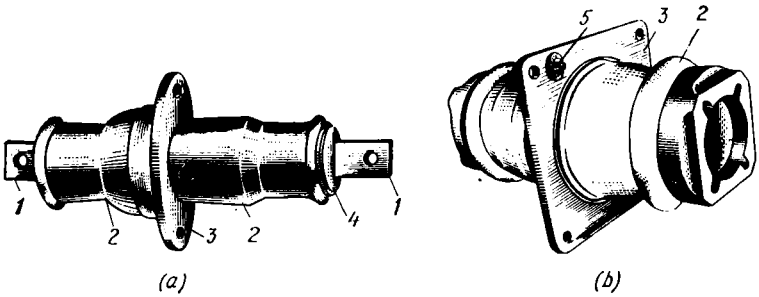


Fig. 14. Bushings

(*a*) П-10/600-375; (*b*) П-10/2000; *1*—conducting bar; *2*—porcelain body; *3*—flanget *4*—steel washers; *5*—earthing bolt

Flange *3* of a bushing is provided with holes to receive fastening bolts and earthing bolt *5* (Fig. 14). Steel washers *4* in the end faces of the bushing secure conducting bar *1* or a conducting rod of circular section.

For current ratings above 1 000 A, use is made of bus-type bushings (Fig. 14*b*) having no current-conducting parts (the bus is passed through the bushing).

The types and mounting dimensions of bushings are presented in Table 2 and Fig. 15

Inspection. In bushings, the porcelain and cemented metal fittings must meet the same requirements as their

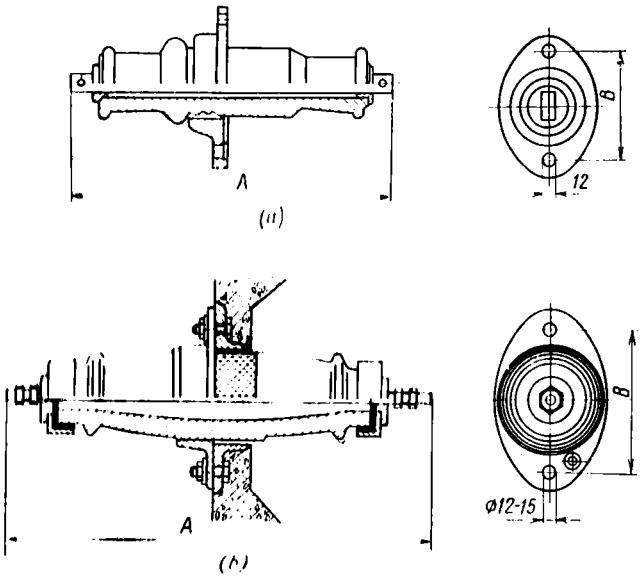
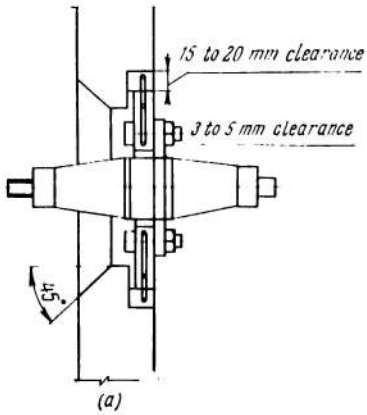


Fig. 15. Dimensions of different bushing types
(*a*) bushing for 6-10 kV, 400-600 A; (*b*) bushing for 6-10 kV, 1000 A

counterparts in support insulators do. Bushings with built-in conductors are also checked to see that the conductors are snugly held in place and their threads are not damaged.

Mounting. Bushings are most frequently secured on reinforced concrete slabs or metalwork (Fig. 16).

When mounting, aligning, and fixing bushings, their centres should fit the longitudinal and transverse laying-out axes. The centre-to-centre distance should conform to the dimension specified in the working drawing.



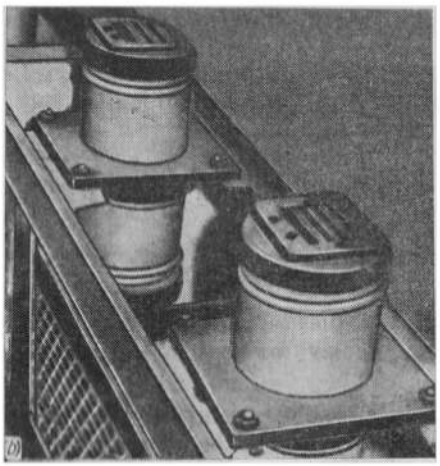


Fig. 16. Bushings mounted on
(*a*) reinforced concrete slab; (*b*) framework of steel angles

Table 2

Types and Mounting Dimensions of Bushings

Type designation	Fig. 15	Dimensions, mm	
		A	*B*
П 6/400-375	*a*	375	132
П 6/600 375	*a*	406	132
П 10/600 750	*a*	425	165
П 6/1000-1250	*a*	625	175
П 10/1000 750	*b*	580	155
П 10/1000 1250	*b*	468	155

Note. The following designations are used: П – bushing; 6, 10 – voltage rating, kV; 375, 750, 1250 – bending load at collapse, kg; 400, 600, 1000 – current rating, A.

Bushings are aligned and levelled by means of a plumb-bob, straight edge and spirit level, a folding rule and a scale. Misalignment is remedied by means of split washers or steel shims.

The flanges of bushings must be earthed as are support insulators.

6. Mounting of Isolators (Disconnecting Switches)

Design and types. Isolators are designed to disconnect specific sections of a circuit first de energized by the associated power switch. Isolators have no arc control devices and therefore must never be operated on circuits with load currents. Small capacitive and no-load currents may be interrupted by isolators, when and if so specified.

Isolators are available in single-pole and three-pole designs.

Considered below is the design of a single-pole isolator designated PBO-10/400 (where P — isolator, B — for indoor use, O — single-pole). The contact system of the isolator is carried by two support insulators *2* fitted to steel base plate *1* (Fig. 17). Movable contact *6* is made up of two copper contact blades, its fixed counterpart being post *3*. On closing the isolator, the contacts are forced together by

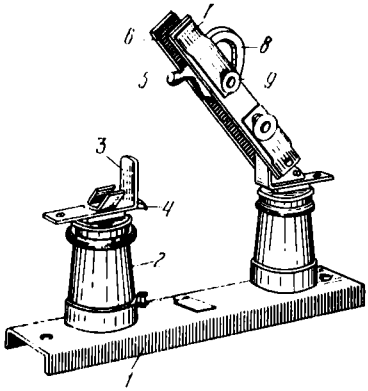


Fig. 17. PBO-10/400 single-pole isolator

1—baseplate; *2*—support insulators; *3*—post; *4*—clamp with projection; *5*—spur; *6*—movable contact; *7*—steel magnetic latches; *8*—eyelet; *9*—spring

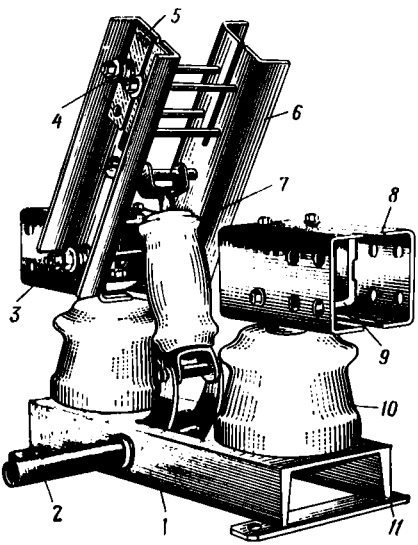


Fig. 18. PBK-10/3000 single-pole isolator

1—baseplate; *2*—shaft; *3*—pin; *4*—spring; *5*—steel plate; *6*—blade; *7*—porcelain tie rod; *8*—fixed contact; 9—cast-iron mount; *10*—ОМД-10 support insulator; *11*—mounting feet

springs *9* maintaining the required contact pressure. During the passage of short-circuit currents the contact pressure is increased by steel magnetic latches *7*. To prevent completely the spontaneous opening of the isolator, it is provided with a suitable lock comprising eyelet *8*, spur *5*, a clamp with projection *4* and a spring (not shown in the figure) that acts

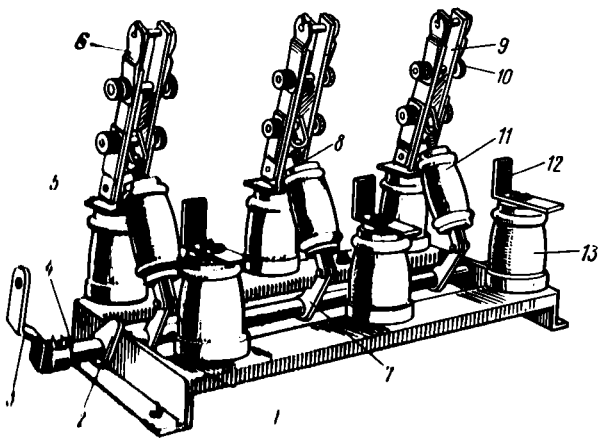


Fig. 19. Three pole isolator

1—steel frame; *2*—stop limiting the angle of isolator shaft rotation; *3*—lever; *4*—shaft; *5*—contact post; *6*—steel plates of magnetic latch; *7* and *8*—steel forks; *9*—links; *10*—moving contact blade; *11*—spring; *12*—rocking porcelain tie rod; *13*—fixed contact; *14*—OMA-10 support insulator

to move spur *5* clockwise. The single-pole isolator is operated by means of a rod, the tip of which is engaged into eyelet *8* to release the lock when opening the isolator.

For currents of 3 000 A and above, use is made of PBK single pole isolators having box-shaped conducting parts in order to improve the conditions of heat removal and to raise mechanical strength. Baseplate *1* (Fig. 18) of an PBK-type single-pole isolator is made of a steel channel with welded mounting feet *11*. Contact blade *6* is rotated on pin *3* by rocking porcelain tie rod *7* hinged on shaft *2*. Fixed contact *8* is held in place by cast-iron mount *9*; the latter and plates *5* form a magnetic latch on closing the isolator. In the course of installation the poles of PBK isolators are connected to form a three-pole unit.

The difference in design between three-pole (Fig. 19) and single-pole isolators is that the three poles of the former have common shaft *4* linked to the contact system by rocking porcelain tie rods *11*. The contact system is arranged on the

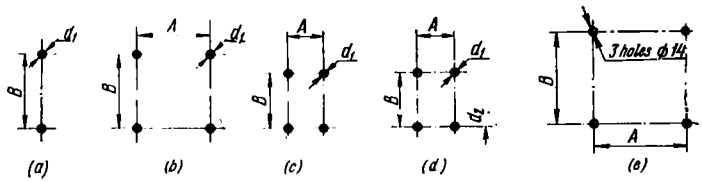


Fig. 20. Mounting dimensions of isolators and operating mechanisms (*a*) PBO; (*b*) PBK; (*c*) ПР-2; (*d*) ПР-3; (*e*) ПЧ-50/15

same principle as that of PBO single-pole isolators. The contact blades are moved in the same manner as in PBK isolators.

The types and mounting dimensions of isolators are presented in Table 3 and Fig. 20.

Table 3

Types and Mounting Dimensions of Isolators

Type designation	Fig. 20	Mounting dimensions, mm			Mass, kg
		A	B	d_1	
PBO-6/400	*a*	—	420	15	7.15
PBO-6/600					7.50
PBO-10/400	*a*	—	420	15	7.10
PBO-10/600					7.60
PB-6/400	*b*	546	280	15	24.00
PB-6/600					24.60
PB-10/400	*b*	646	280	15	26.50
PB-10/600					27.10
PBK-10/3000	*b*	200	455	18	170.00
PBK-10/4000					200.00

Note. The following designations are used: P — isolator; B — for indoor use; O — single-pole; K — box-type; first number — voltage rating, kV; second number — current rating, A. Except for those combined into three-pole units, single-pole isolators are operated by rods.

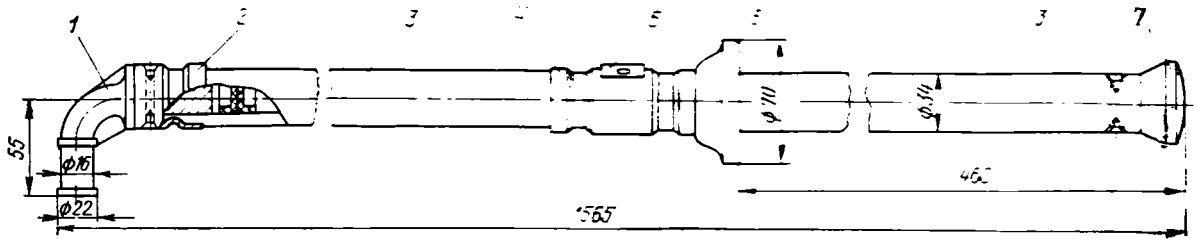


Fig. 21. ШР-20 rod

1, 7—tips; *2*—yoke; *3*—tubes of phenolic resin plastic; *4*—couplings; *5*—nameplate; *6*—stop

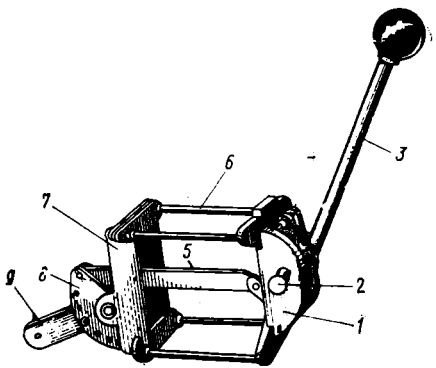


Fig. 22. ПР-2 lever-type operating mechanism

1—front bearing; *2*—detent; *3* and *9*—levers; *4*—projection; *5*—force link; *6*—studs; *7*—rear bearing; *8*—sector

A rod of the ШР-20 type (Fig. 21) is made up of two tubes *3* of phenolic resin plastic held together by steel coupling *4*. The coupling is press-fitted on the ends of the tubes and expanded into place. Secured to the coupling is nameplate *5* with the rod specifications. The lower plastic tube carries stop *6* separating the working portion of the rod from its handle. To safeguard the insulation against mechanical da-

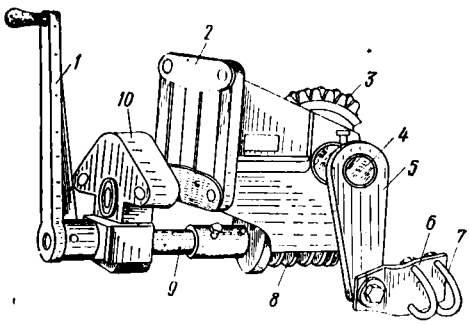


Fig. 23. ПЧ worm-gear operating mechanism

1—crank arm; *2*—rear bearing; *3*—worm gear; *4* and *9*—shafts; *5*—lever; *6*—gib; *7*—clip; *8*—worm; *10*—body

mage, steel yoke *2* is press-fitted on the upper non-conducting end of the rod. Tip *1* is press-fitted into the tube hole and pinned to the tube and yoke *2*.

End piece *7* is press-fitted into the hole in the lower end of the tubular handle.

Three-pole isolators and РВК single-pole isolators combined into three-pole units are controlled by suitable operating mechanisms.

The simplest in design are ШР-2 (Fig. 22) and ПР-3 lever-type operating mechanisms intended for isolators rated up to 600 and 2 000 A, respectively. A lever-type operating mechanism is made up of front and rear bearings, *1* and *7*, held together by studs *6*. When control lever *3* is moved up or down, it acts, via the medium of force link *5* and sector *8*, on lever *9* coupled to the controlled isolator with a tie rod. In both the closed (upper) and the open (lower) positions, lever *3* is locked by detent *2* that should be pulled back by the operator for the time of operation. The tie rod coupl-

ing the operating mechanism to the isolator installed in the same plane can be attached directly to projection *4* of the control lever.

Isolators rated for 3 000 A and above may be actuated by worm-gear operating mechanisms of the ПЧ type (Fig. 23) or by electric-motor-driven operating mechanisms of the МРВ type (the letter М stands for "motor"). Rotated crank arm *1* of a worm-gear operating mechanism acts, via the medium of shaft *9*, on worm *8* and worm gear *3*; the latter rotates shaft *4* thus moving lever *5* and gib *6*. A tie rod coupled to the controlled isolator is attached to gib *6* with clip *7*. The electric motors of МРВ operating mechanisms are remotely controlled (from a control panel). The types and mounting dimensions of operating mechanisms are presented in Table *4* and Fig. 20.

Table 4

Types and Mounting Dimensions of Isolator Operating Mechanisms

Type designation	Fig. 20	Mounting dimensions, mm					Mass, kg
		A	*B*	*C*	d_1	d_2	
ПР-2	*c*	70	120	100	12	—	3.5
ПР-3	*d*	80	160	165	13	10	8.0
ПЧ-50/15	*e*	150	120	—	—	—	24.4

Inspection. Before they may be mounted, isolators should be thoroughly inspected. The contact surfaces should not be pitted, oxidized, or bent. An isolator with bent contact surfaces should be repaired.

The blades should enter the fixed contacts smoothly and without bumping. Otherwise, it may be necessary to either shift the insulators of the fixed contact or place steel shims under them.

The blades and the fixed contacts may also come slightly loose on their insulators. The mating of the contacts is checked with a clearance gauge which should not go more than 0.6 mm between the contacts. The proper mating of line

contacts may be indicated by the marks formed on the surface of the contact blade by repeated closing and opening.

Checked in the course of inspection are the condition of the isolator contact springs and the contact pressure they maintain. The pressing force is measured with a dynamometer. Table 5 gives the data on the minimum force required to pull a blade from its fixed contact in isolators of different types. When checking the contact pressure, the contacts are freed of grease.

Table 5

Minimum Force Required to Pull Isolator Blade from Its Fixed Contact

Isolator current rating, A	Pull, kg	Isolator current rating, A	Pull, kg
400	10	2000	40
600	20	3000 (PBK)	50-56
1000	40	4000 (PBK)	33-36
1500	40	5000-6000 (PBK)	50-55

The blades should be able to move through the angles specified by the manufacturer. These angles for some of the isolators are given in Table 6.

Table 6

Angles of Blade Rotation for Some Isolator Types

Type of isolator	Current rating, A	Angle when fully open, deg.
PBO	400, 600	75
PB	400, 600	65
PBK-10	3000, 4000	58

The porcelain insulation of isolators must meet the same requirements as the porcelain of support insulators and bushings.

Operating mechanisms are checked for completeness, and their machinery for serviceability.

Mounting. Positions for isolators should be marked out so as to match the dimensions given in Figs 20*a* and *b* and Table 3.

Isolators are most frequently mounted on metalwork and secured with bolts 45-50 mm long (Fig. 24).

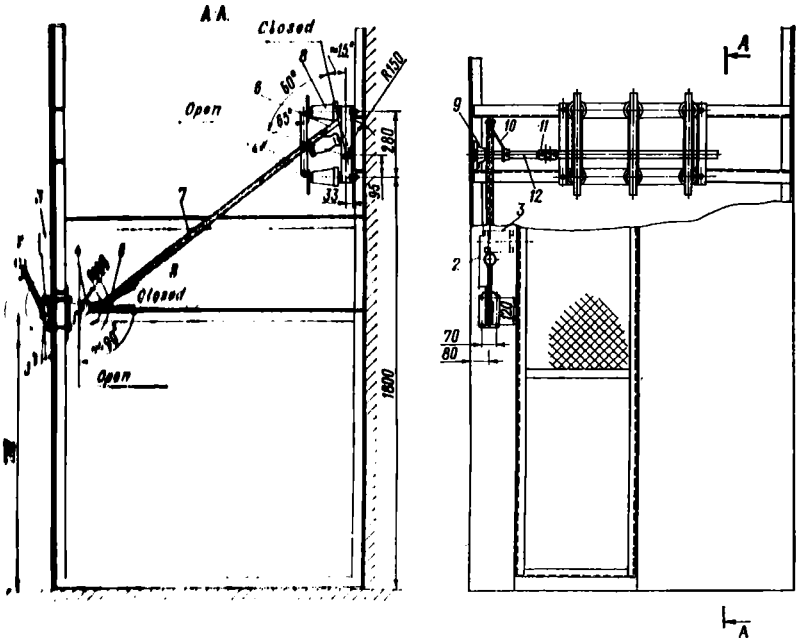


Fig. 24. Isolator and its operating mechanism mounted on metalwork

1 operating mechanism; *2* tie bar to KCA auxiliary switch; *3*– auxiliary switch; *4* sector lever of operating mechanism; *5* lever of operating mechanism; *6* adjusting clevises; *7* tie rod; *8*– isolator; *9*– auxiliary bearing; *10*—isolator actuating lever; *11*– isolator shaft-to-extension shaft coupling; *12*—extension shaft

When mounted of necessity directly on a brickwork or concrete base up to 100 mm thick, isolators are secured with long through bolts. On the opposite side of the base, either construction washers are welded to the bolts or steel angles are embedded to pass the bolts through. Low-duty isolators may be secured to brickwork or concrete bases over 100 mm thick with anchor studs.

When mounting isolators, it is advisable to use a ПГП-0.25 hoisting device (Fig. 25) comprising winch *1*, block 2, rope 3, and suspension *4*. The device is designed to hoist loads up to 250 kg and can be operated both manually and electrically. In mounting isolators, use is made of steel slings, including the general-purpose one depicted in Fig. 26.

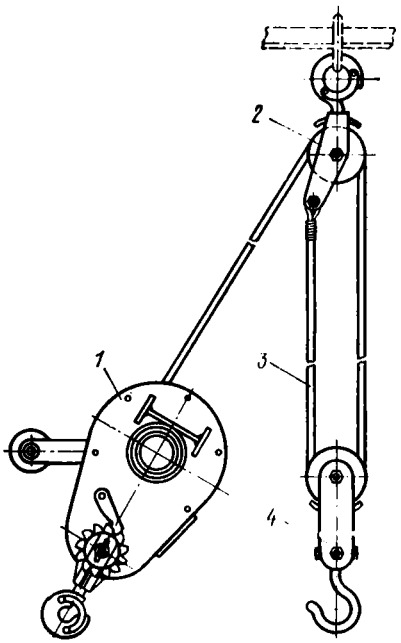


Fig. 25. Hoisting device ПГП-0.25

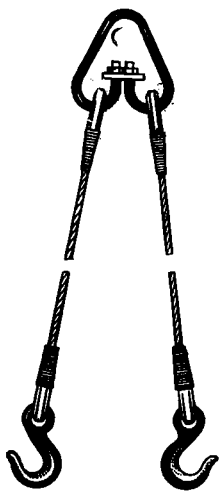


Fig. 26. General-purpose sling

An isolator is temporarily secured in place with nuts run down their bolts and then plumbed and levelled with a plumb bob and a straight edge with spirit level. Care must be taken to see that the axes of the isolator mounting holes are coincident with the laid-down axes within ± 2 mm.

Misalignment is eliminated by inserting steel shims under the baseplate where required. The isolator is clamped down by gradually tightening the nuts across in turn. In so doing, the shaft should be checked at intervals for free movement

when rotated by hand. The jamming of the shaft will point to a misalignment that needs to be remedied.

If an operating mechanism is placed aside from the isolator it controls (see Fig. 24), the isolator is provided with extension shaft *12* fastened to the shaft with coupling *11* which is secured with steel taper pins 5-6 mm in dia and 50-60 mm long. The coupling is drilled, together with the shaft, when installed in position. The hole diameter should be 0.2-0.3 mm under the pin diameter. The coupling is pinned or electrically welded to the extension shaft in a workshop. The other end of the extension shaft is carried by bearing *9* as shown in Fig. 24.

Operating mechanisms are mounted in the same manner as isolators. The isolator is coupled to its operating mechanism with tubular tie rod *7* (see Fig. 24) made of 3/4-inch steel pipe. The ends of the tie rod have adjusting clevises *6*.

Once the isolator is coupled to its operating mechanism, the angle of blade rotation is checked for conformity with the manufacturer's specifications (see Table 6). Should there be any difference, the required correction is introduced by shifting the adjusting clevises, the initial position of which on the bolts must be midway so as to extend the range of adjustment. With a considerable difference, the angle of rotation can be changed by selecting a hole of the required diameter in sector lever *4* of the operating mechanism (see Fig. 24). At this point the alignment of the contact blades and fixed contacts is also checked and adjusted if necessary; the blades should move smoothly, without bumping against the fixed contact, either straight or sideways. The blades of the three phases should touch their fixed contacts simultaneously, the difference between the blade positions on closing not exceeding 3 mm. This is achieved by altering the length of force links *8* (see Fig. 19).

The adjustment completed, lever *3* is finally fitted to the isolator shaft. The lever and the shaft are drilled with an electric drill and secured together with a pin 6 mm in dia and 60 mm long.

An installed isolator should be checked for proper operation. Repeated closing and opening should not cause misalignment, deformation of the tie rods, maladjustment of the system, vibration. Care must be taken to see that the lost

motion of the control lever does not exceed 5 degrees. For this purpose, clearances in the joints are reduced and the adjusting clevises tightened on the tie rod.

Mounting of KCA auxiliary switches. The isolator-operating mechanism system is normally complemented by a KCA auxiliary switch installed at the same time as the operating mechanism. The function of the auxiliary switch is to con-

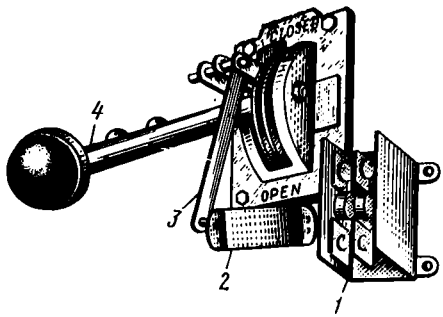


Fig. 27. KCA auxiliary switch coupled to operating mechanism
1—contacts; *2*—lever; *3*—link; *4*—control lever of operating mechanism

nect the signalling circuits employed to indicate (on the control panel) whether the isolator is closed or open.

As lever *2* (Fig. 27) of the auxiliary switch is rotated, the movable contacts of the switch are shifted to make one signalling circuit and break the other. The auxiliary switch is coupled, with link *3* of steel strip, to the control lever of the operating mechanism and can be placed either above (see Fig. 24) or below (see Fig. 27) the latter.

The proper operation of a KCA auxiliary switch is as follows:

on closing the isolator, the CLOSED signalling circuit should be made before the contact blade of the isolator enters its fixed contact (the blade is about 5 degrees short of its end position);

on opening the isolator, the OPEN signalling circuit should be made at the instant the contact blades have covered 75 percent of their full travel.

After overall adjustment the isolator should be given a number of trial openings and closings. At the same time the

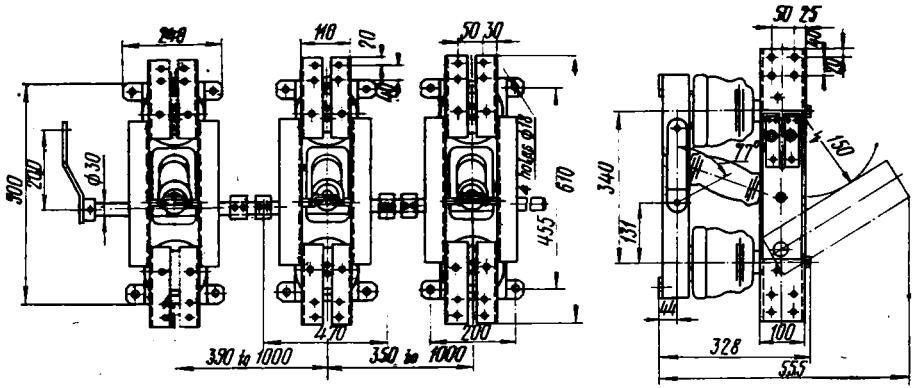


Fig. 28. PBK-10/3000 isolator assembly

rubbing parts and contacts should be wiped with a rag moistened with petrol, then with a dry rag, and lubricated with petroleum jelly. The rubbing surfaces in the purely mechanical linkages should be lubricated with grease. The greased parts should be wrapped in paper to shut out dirt and dust during installation.

Mounting of PBK isolators. Single-pole PBK isolators are combined into three-pole units in the course of installation. The poles may be spaced on 350 to 1 000-mm centres according to design data. If the centre-to-centre distance does not exceed 470 mm, the shafts of individual units are joined with one coupling (two couplings for three poles). For spacings over 470 mm, the number of couplings is doubled and a steel distance piece is installed between the two couplings of each joint.

Figure 28 depicts a three-pole unit made up of PBK-10/3000 isolators. As seen from the picture, the couplings are secured with taper pins 6 mm in dia and 60 mm long. For this purpose, the couplings and the isolator shaft are simultaneously drilled with an electric drill.

When mounting an isolator, its operating mechanism is installed and then coupled to the isolator with a tubular tie rod.

An PBK isolator installed with a ПЧ worm-gear operating mechanism is shown in Fig. 29. When coupled, both the isolator and the operating mechanism are set to the CLOSED position. The tie rod of 1-inch steel pipe is secured in place. The levers on the shafts of the isolator and operating mechanism are temporarily locked with bolts.

To check the angle of blade rotation, the crank arm of the operating mechanism is rotated 12 revolutions counterclockwise and the isolator is given a trial opening, which should move its contact blades through the angle specified in the drawing. The required adjustments can be made by altering the angles through which the levers of the isolator or those of the operating mechanism rotate, and also by shifting the tie rod lengthwise. The levers on the shafts of the isolator and operating mechanism are drilled and fixed by pins. At the same time, the nuts are tightened of the screw clips securing the tubular rod at the operating mechanism.

Also installed in the course of mounting are auxiliary

switches coupled to the operating mechanism with a link made of steel strip or round bar.

Mounting of isolators in units. A widely used advanced technique of switchgear installation is the use of preassembled isolator units. In a workshop isolators are com-

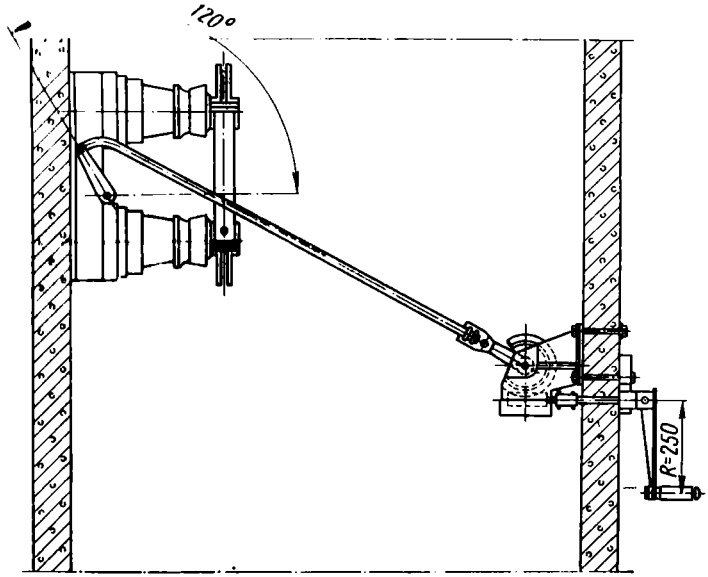


Fig. 29. Isolator mounted with worm-gear operating mechanism

bined into units complete with operating mechanisms coupled to the isolators with tubular tie rods. Concurrently, RCA auxiliary switches are installed and linked to the control lever of the operating mechanism. The assembled units are brought to the site and mounted to specifications.

7. Mounting of Load-Breaking Isolators

Design. Load-breaking isolators differ from three-pole isolators in having an arc-control device. A BH-16 load-breaking isolator is designed to interrupt load currents up to 400 A and hence protected against short-circuit currents

by built-in ПК fuses. Complete with the fuses, the unit is referred to as the ВНП-16 load-breaking isolator.

The load-breaking isolator (Fig. 30) comprises two current circuits, load-carrying and arc-control, the first of these featuring contacts *7* and *9*, and the second, contacts *5* and *8*. The arcing contacts are located ahead of the load-carrying ones (see the position of contacts *8*, *9* and *5*, *7*). Therefore,

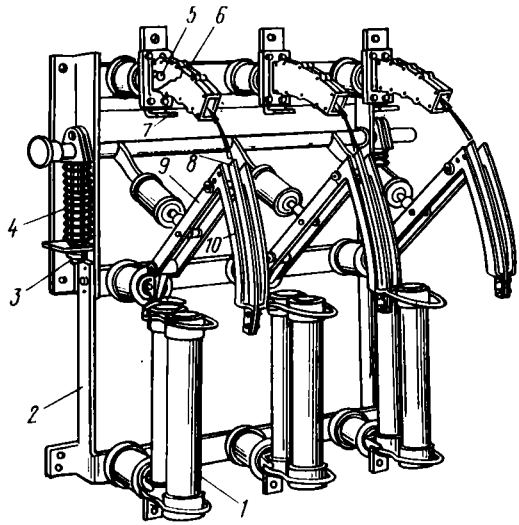


Fig. 30. ВНП-16 load breaking isolator

1—ПК fuse; *2* - fuse frame; *3*—rubber washers; *4*—opening spring; *5*—fixed arcing contact; *6*—plastic arc chute; *7*—fixed load-carrying contact; *8*—moving arcing contact (blade); *9*—moving load-carrying contact; *10*—steel strips

the arc-control circuit is completed earlier and interrupted later than the load-carrying one, for which reason an electric arc, should it strike, is confined to the arc-control circuit.

The mounting dimensions of a ВНП-16 load-breaking isolator are given in Table 7 and in Figs 31*a* and *b*; the mass of the isolator is 64 kg.

Load-breaking isolators are controlled with operating mechanisms of the ПРА-12 type (automatically tripped leverage) of 16 kg mass and the ПР-16 type of 6 kg mass; the mounting dimensions of these mechanisms are presented in Fig. 31*c*.

Table 7

Mounting Dimensions of BHII-16 Load-Breaking Isolator

Dimensions (Fig. 31b)	Dimensions by fuse type, mm					
	ПК-6/30	ПК-6/75	ПК-6/150	ПК-10/30	ПК-10/50	ПК-10/100
A	703	758	758	803	858	858
B	680	680	680	680	680	680

Load-breaking isolators may as well be used complete with ПС-10 solenoid-type operating mechanisms designed for remote control.

Also available is a ВНП-17 load-breaking isolator which differs from the ВНП-16 in having an automatic cutout actuated by the blow-out of any one of the three fuses.

Inspection. Load-breaking isolators are externally inspected to see that plastic arc chutes *6* (see Fig. 30) are intact and have gas generating plastic packs fitted in. Special attention is placed on checking the contact blades. Arcing contact blade *8* must not be bent and it must enter the gas-generating pack easily and positively. The porcelain must meet the same requirements as in support insulators.

The shaft and the contact blades are also checked for angle of rotation. The shaft, when rotated through 71-73°, must cause the load-carrying contact blades to turn through 58°. The arcing contact blades must travel 160 mm in the arc chutes.

Mounting. The procedure for securing a load-breaking isolator and its operating mechanism in place is generally the same as with an ordinary isolator.

The isolator is coupled with its operating mechanism by means of a tie rod made from 3/4-inch steel pipe. Adjusting clevises are either pinned or welded to both ends of the tie-rod pipe. In selecting the length of the tie rod and the hole in the sector lever, one must take into account that the most favourable conditions for the joint performance of the isolator and its operating mechanism are provided if the ratio *b/a* is 2.5 (Fig. 32) in the closed position.

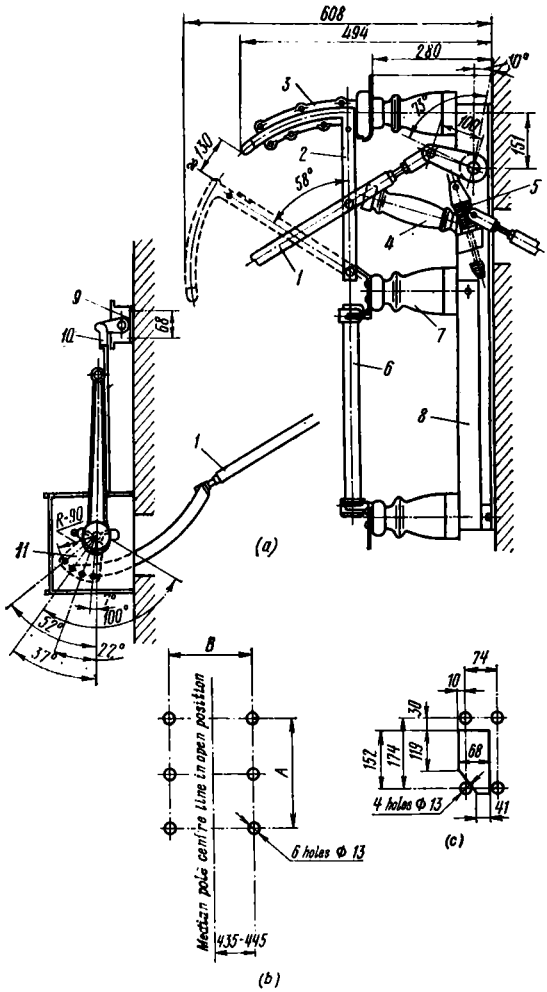


Fig. 31. ВНП-16 load-breaking isolator with ПРА-12 operating mechanism

(*a*) mounting and adjustable angles; (*b*) mounting dimensions of isolator; (*c*) mounting dimensions of operating mechanism; *1*—tubular tie rod; *2*—moving contact assembly; *3*—arc-control device; *4*—porcelain link; *5*—opening spring; *6*—ПК fuse; *7*—support insulator; *8*—isolator frame; *9*—auxiliary contacts; *10*—tie rod between operating mechanism and auxiliary contacts; *11*—sector lever of operating mechanism

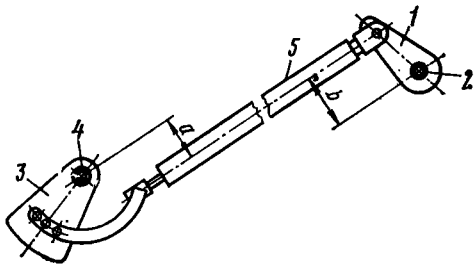


Fig. 32. Ratio of effective lever arms for isolator and operating mechanism taken into account in selecting the length of tie rod

1—isolator lever; *2*—isolator shaft; *3*—operating mechanism lever; *4*—operating mechanism shaft; *5*—tie rod

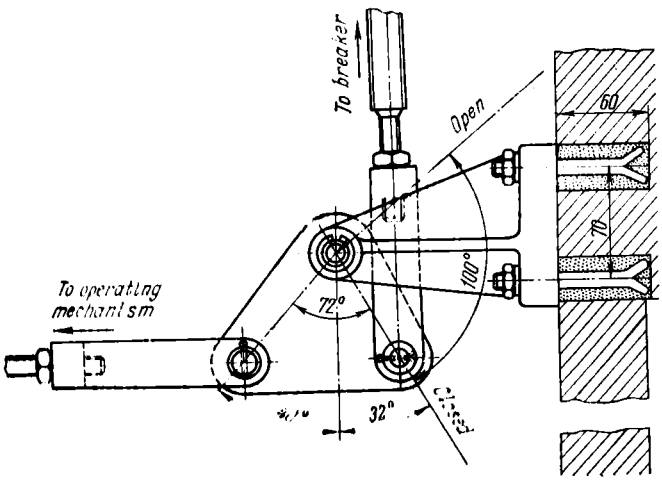


Fig. 33. Arrangement of tie rods and intermediate bearing with fuses located above isolator on outgoing lines

Current standards require that a load-breaking isolator be installed with its fuses located forward of the unit (as viewed in the direction of power transmission). On outgoing lines, the fuses are therefore located above the isolator. Since the fuses must be made accessible for service by placing them at a suitable height, the operating mechanism is coupled to the isolator through an intermediate bearing (Fig. 33).

Once adjusted for joint operation, a load-breaking isolator and its operating mechanism must meet the following requirements:

the arcing contact blades should enter the arc chutes freely and precisely for a distance of 160 mm;

the load-carrying contact blades should enter, when closing the isolator, the fixed contacts smoothly and without bumping sideways and assume a strictly vertical position;

on opening the isolator, the load-carrying contacts should be separated by an angle of 58°;

the other adjustable angles should all be as specified in Fig. 31;

the isolator should be opened by the action of the opening spring as the operating mechanism control lever is turned downwards through an angle close to 15°.

8. Mounting of ВМП-10 Oil Circuit Breakers

The ВМП-10 oil circuit breaker is a suspension-type low-oil content unit designed for 10-kV service and available in current ratings of 600, 1 000, and 1 500 A.

Tanks *4* of the circuit breaker (Fig. 34) are secured on support insulators *3* mounted on steel frame *2*. The frame of the circuit breaker is cushioned against shocks by built-in spring buffer *1* when closed and by built-in oil dashpot *5* when opened. The contact system of the unit is actuated by tie rod *6* linked to the shaft. Opening spring *7* is acting to force the circuit breaker into opening.

Cylinder *1* of the tanks (Fig. 35), made of insulating material (epoxy glass), have metal flanges *2* with covers *4* on their bases. Secured on the covers are fixed cluster contacts *3*. Cylinder *1* mounts, in its upper portion, housing *14* of aluminium alloy accommodating moving contact rod *8* linked to the circuit breaker shaft by insulating tie rod *6* (see Fig. 34). Also installed in housing *14* (see Fig. 35) is current collector *9* fastened on guide rods *15*.

On closing the circuit breaker, current flows through terminal *16*, current collector *9*, moving contact rod *8*, cluster contact *3*, and lower terminal *5*. Arc chute *7* is located above the cluster contact.

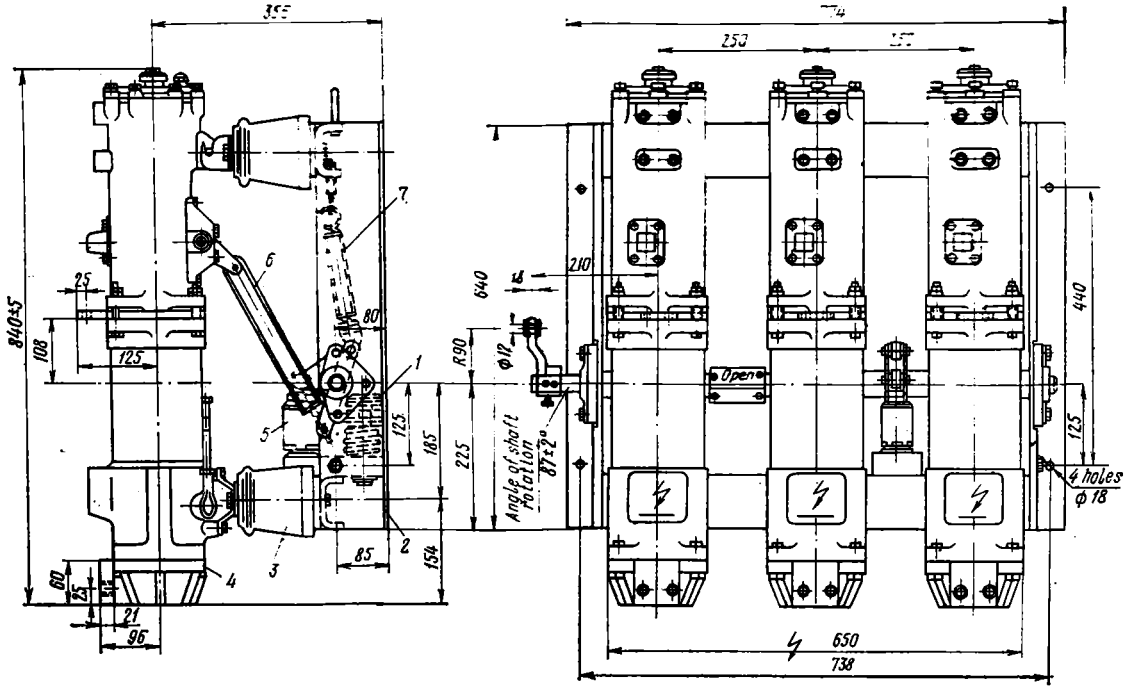


Fig. 34. ВМП-10 oil circuit breaker. General view and mounting dimensions

1—spring buffer; *2*—steel frame; *3*—support insulators; *4*—tanks; *5*—oil dashpot; *6*—tie rod; *7*—opening spring

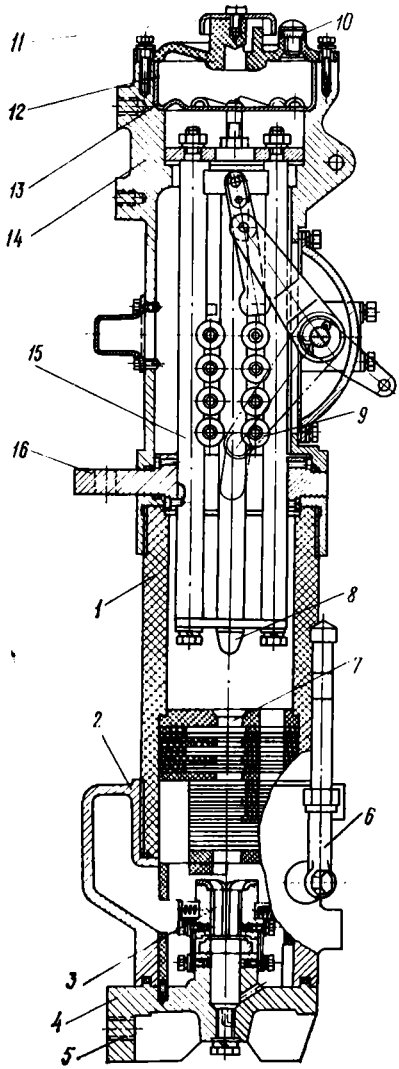


Fig. 35. ВМП-10 breaker pole

The unit is provided with oil separator *13* having cover *12* and cap *11* (in the upper portion) and oil gauge glass *6* (in the lower portion). An oil-filling hole in the cover is fitted with threaded plug *10*.

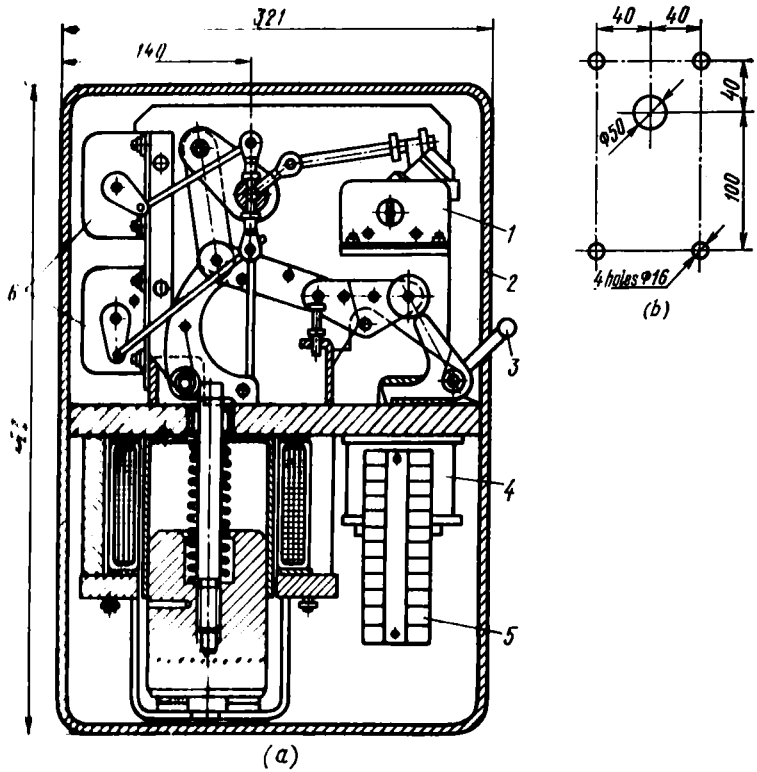


Fig. 36. ПЭ-11 electromagnetic operating mechanism

(*a*) arrangement; (*b*) mounting dimensions; *1*—auxiliary contacts of control circuit; *2*—protective housing; *3*—hand-trip lever; *4*—opening coil with antijumping interlock contact; *5*—cleat; *6*—auxiliary switch contacts

The main mounting dimensions of the ВМП-10 circuit breaker are given in Fig. 34. Its versions rated for 600, 1 000, and 1 500 A have a dry mass of 140, 145, and 160 kg, respectively. The circuit breaker takes 4.5 kg of oil.

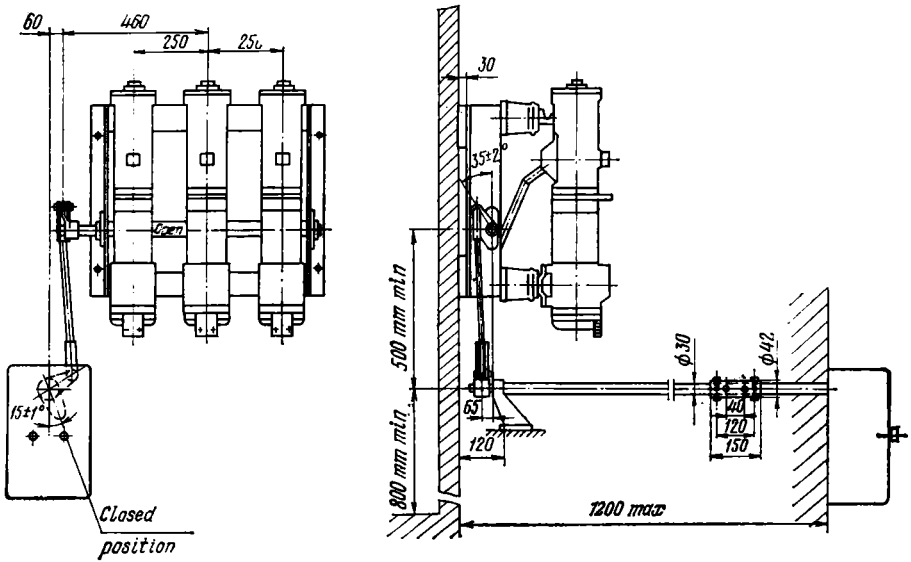


Fig. 37. ВМП-10 oil circuit breaker mounted with ПЭ-11 operating mechanism

Inspection. The unit brought to the erection site is inspected and checked for completeness. To inspect the interior of the unit, the lower cover with the fixed cluster contact is removed and the distance sleeve and the arc chute taken out.

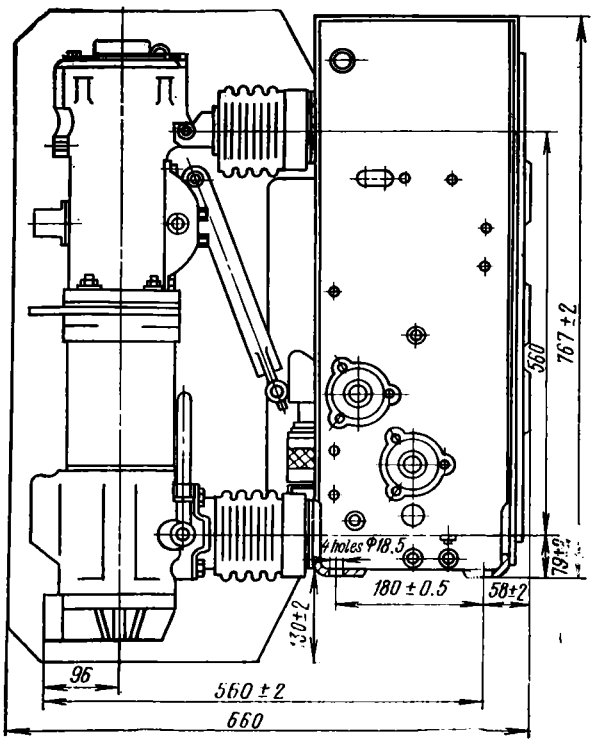


Fig. 38. ВМП-10П oil circuit breaker with built-in ПЭ-11 operating mechanism

Mounting. Once the circuit breaker is inspected, its frame is installed in place to take on the poles. Before the poles are mounted on the frame, their mechanisms are checked for easy motion by turning manually the levers accessible from outside. The shaft of the circuit breaker is checked

for free rotation, with the opening springs disengaged. The poles in position, the circuit breaker is coupled to its operating mechanism with a tie rod of 3/4-inch steel pipe.

The ВМП-10 circuit breaker is operated by a ПС-10М modernized solenoid-type mechanism, or a ПЭ-11 electro-

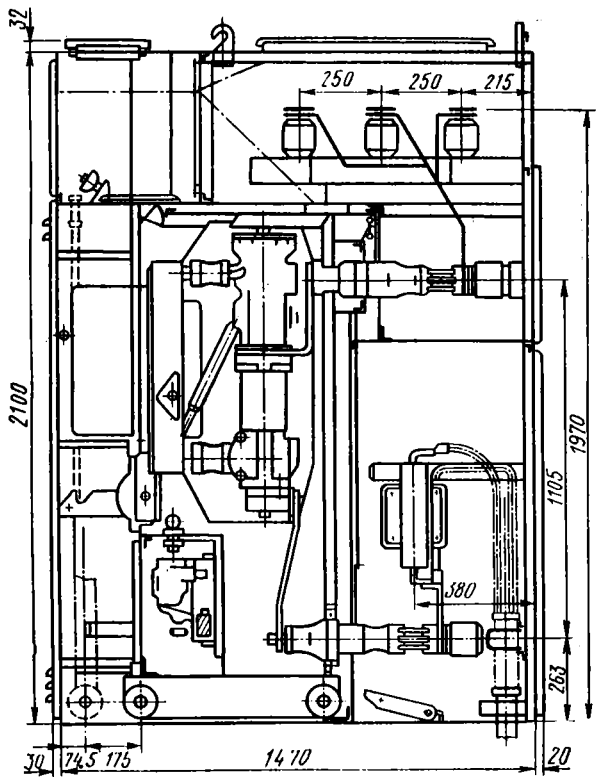


Fig. 39. Series К-111у КРУ unit with ВМП-10К oil circuit breaker and ПЭ-11 operating mechanism

magnetic mechanism (Fig. 36), or spring-actuated mechanisms of the ПП-61, ППМ-10 and other types.

Figure 37 depicts a ВМП-10 circuit breaker coupled to a ПЭ-11 operating mechanism. Brought to a commercial

level has been the manufacture of a ВМП-10П circuit breaker with a built-in spring-actuated operating mechanism (Fig. 38). Fig. 39 shows a ВМП-10К circuit breaker with a ПЭ-11 operating mechanism mounted in a КРУ unit.

Adjustment of ВМП circuit breakers. When adjusting a circuit breaker in conjunction with its operating mecha-

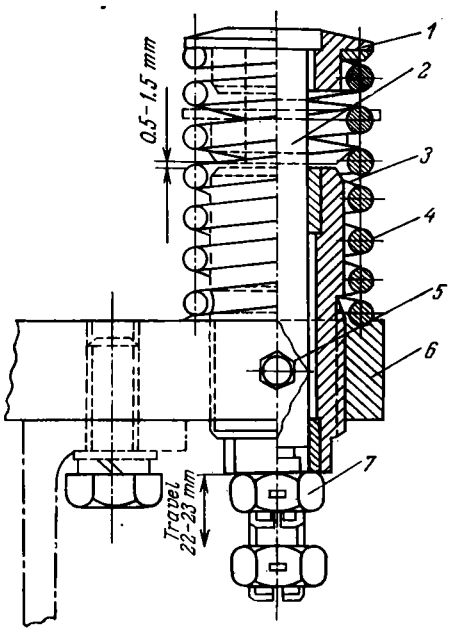


Fig. 40. Spring buffer

1—head; *2*—rod; *3*—bush; *4*—spring; *5*—retainer screw; *6*—mount; *7*—nut

nism, one should take into account that the moving contact rods must be free to travel 240 to 245 mm. The moving contact rods should enter (sink into) the cluster contacts by 55-63 mm in units rated for 1 000 A and by 52-60 mm in units rated for 1 500 A. The moving contact rods should enter their cluster contacts all at a time, with the difference, if any, in their positions not exceeding 5 mm. In the closed position, a clearance of 0.5-1.5 mm should be provided in

the spring buffer of the circuit breaker, the travel of the spring being within 22-23 mm (Fig. 40). In the oil dash-pot, the piston stroke should be within 16 mm.

Once installed in place, the circuit breaker is filled with dry transformer oil. In the open position, the oil level should remain between the two lines marked on the oil gauge glass.

9. Mounting of МГГ-10 Oil Circuit Breakers

The МГГ-10 is a generator oil circuit breaker intended for use in circuits with heavy (generator) currents at voltages

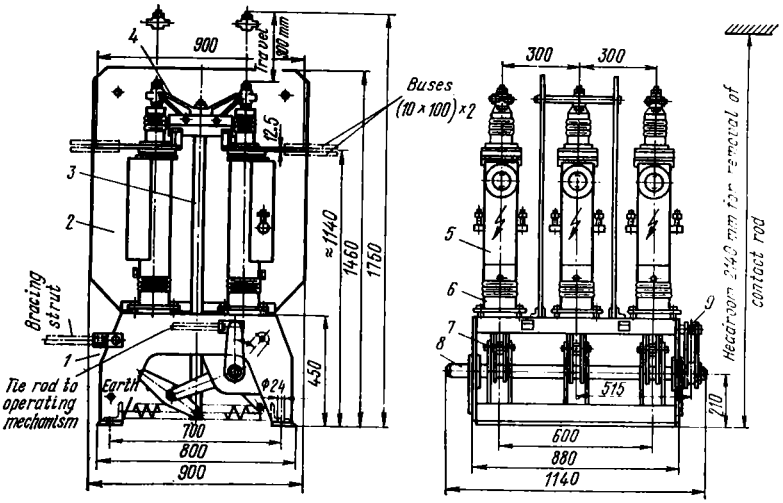


Fig. 41. МГГ-10 oil circuit breaker

1—frame; *2*—insulating barrier; *3*—insulating lift rod; *4*—silumin cross-head with moving contacts; *5*—pot cylinder; *6*—support insulator; *7*—operating mechanism; *8*—shaft; *9*—linkage

up to 10 kV. It is designed for indoor installation in dry, heated and unheated locations. These circuit breakers are available in current ratings of 2 000 and 3 000 amperes. They are built into КРУ and КРУН switchgear cells. The main dimensions of an МГГ-10 circuit breaker are given in Fig. 41.

The dry mass of an МГГ-10 breaker is 580 to 600 kg, and its six pots take 20 kg of oil.

МГГ-10 circuit breakers are operated by a ПЭ-2 mechanism (Fig. 42) of 173 kg mass.

Visual inspection. Once on the erection site, the circuit breaker, still in its packing crate, should be immediately

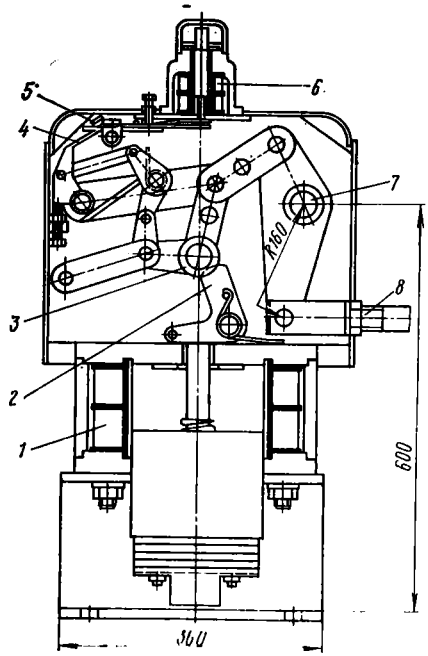


Fig. 42. ПЭ-2 solenoid operating mechanism (in closed position)

1—closing coil; *2*—latch; *3*—roller shaft; *4*—trip-free mechanism; *5*—safety bolt plate; *6*—opening coil; *7*—shaft; *8*—tie rod to breaker

taken into a dry room, checked for damage to the packing crate, unpacked, taking care to avoid any injury to the contents, and examined for breakage caused during transportation. At the same time the contents are checked against the packing list for missing parts.

If visual inspection reveals moisture on the other surfaces, the sleeves of phenolic resin plastic of the pots and the arc-

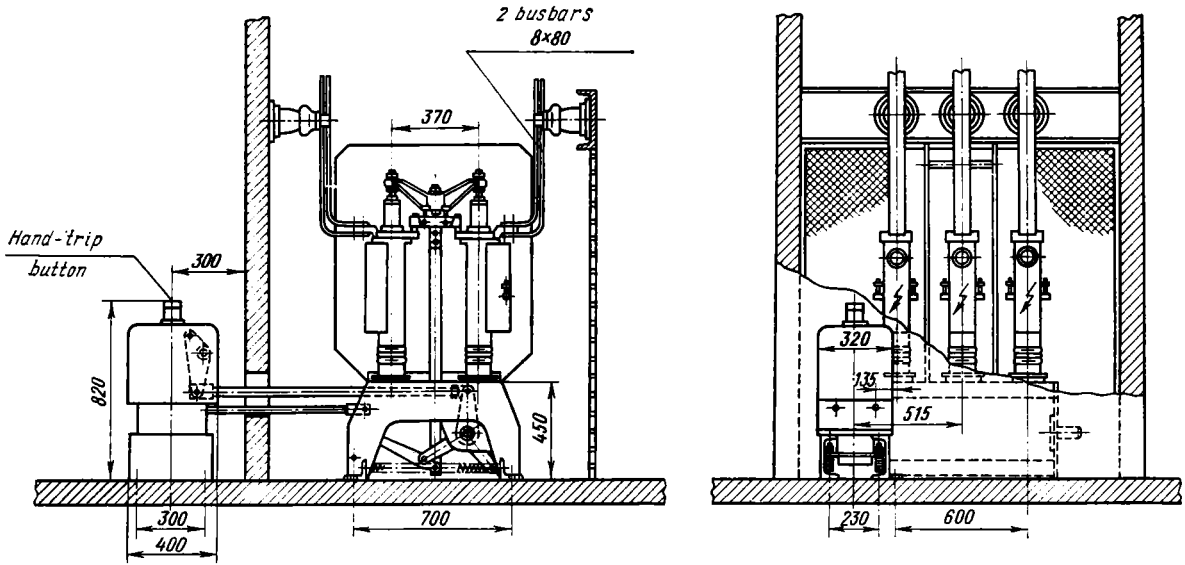


Fig. 43. МГГ-10 breaker with ПЭ-2 operating mechanism

control chambers must be examined thoroughly. If these parts are found to be moist, they must be allowed to dry in an oven at 80° to 90°C for 48 hours, or kept submerged in dry transformer oil at 70° to 80°C for the same interval of time.

Mounting. The circuit breaker and its operating mechanism are pulled to their cell by an electric winch. The mounting

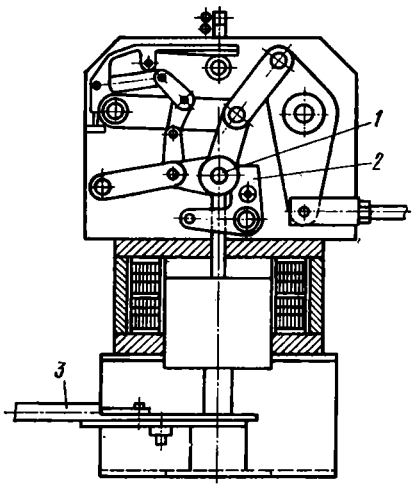


Fig. 44. Operating mechanism pushed past its closed position

dimensions are given in Fig. 43. The circuit breaker and its operating mechanism are secured to the foundation with M20 bolts.

While being mounted, the circuit breaker and its operating mechanism are carefully plumbed and levelled in their respective positions; their operating levers linked by a tie rod must be in one plane. On completion of alignment, the nuts of the fastening bolts are tightened and a bracing strut is installed, whereupon the circuit breaker and its operating mechanism are again checked for proper location.

Inspection. Prior to mounting, the unit is usually inspected, for which purpose the cross-head is removed, the arcing rods taken out, and pot cylinders disassembled. The

first operation is to release the shackle which has kept the circuit breaker mechanism in the closed position. This is done by pushing the operating mechanism past its closed position by hand so that roller shaft *1* (Fig. 44) stops somewhat short of latch *2*. Then the circuit breaker is coupled to the operating mechanism by the tie rod, and the unit is closed, thus relieving the shackle of tension. The shackle is removed and the breaker is slowly opened.

To close and open the circuit breaker by hand at the time of mounting and adjustment, use is made of jack *3* located centrally under the lower end of the operating mechanism core. A 1 1/4-inch pipe 1 to 1.5 m long fitted on the jack handle facilitates the task.

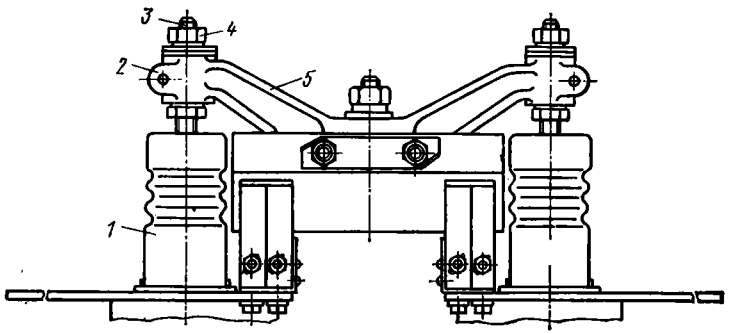


Fig. 45. МГГ-10 breaker contact system. Upper portion
1—bushing; *2*—coupling bolt; *3*- arcing rod; *4*—nut; *5*—silumin cross-head

Once open, the circuit breaker is partially disassembled in order to examine specific parts. Nut *4* (Fig. 45) is unscrewed and coupling bolts *2* holding arcing rods *3* in silumin cross-head *5* are slackened. The arcing rods are then lowered until they come abutt with the bases of fixed cluster contacts *4* (Fig. 46). Next insulating lift rods *3* (see Fig. 41) are detached from the breaker mechanism (Fig. 47) and removed along with the cross-heads. This done, the arcing rods are removed and the disassembly of the pot cylinders is started.

Disassembly and assembly of pot cylinders. First covers *13* with bushing insulators (see Fig. 46) are removed and

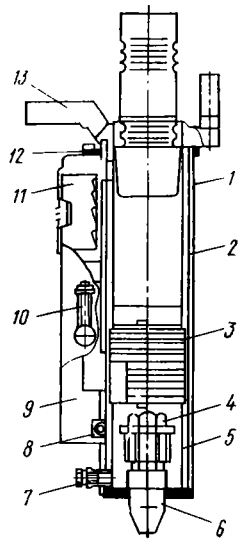


Fig. 46. Section through breaker pot cylinder

1—steel cylinder; *2*—upper distance sleeve of phenolic resin plastic; *3*—arc-control chamber; *4*—cluster contact; *5*—lower sleeve of phenolic resin plastic; *6*—boss; *7*—oil-drain plug; *8*—ball valve; *9*—tank; *10*—oil gauge glass; *11*—oil separator; *12*—oil-filling hole with plug; *13*—cover with bushing

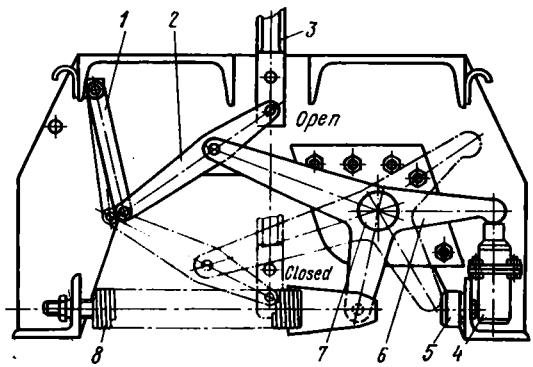


Fig. 47. Circuit breaker mechanism

1—suspension arm; *2*—rocker; *3*—insulating lift rod; *4*—oil dashpot; *5*—limit stop; *6*—curved lever; *7*—shaft; *8*—opening spring

then sleeves *1* of phenolic resin plastic and arc-control chambers *2* (Fig. 48) are taken out with care.

Cluster contact *4* is examined and checked without taking it out of the cylinder. This is done using a lamp connect-

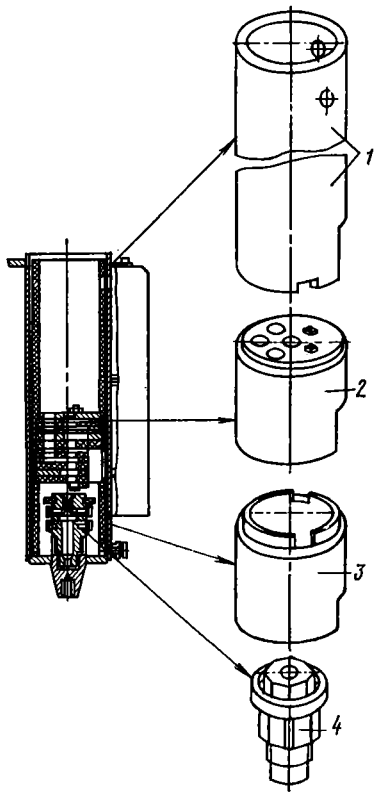


Fig. 48. Arrangement of cylinder parts

1—upper insulating sleeve of phenolic resin plastic; *2*—arc-control chamber; *3*—lower insulating sleeve of phenolic resin plastic; *4*—cluster contact

ed to 12 V supply and lowered into the cylinder. If the serviceability of the cluster contact is open to question, it has to be removed with the use of a suitable spanner supplied by the manufacturer.

The inside of the cylinders is washed with clean transformer oil. At the same time the holes provided in the cylinders to connect oil gauge glasses *10* and valves *8* (see Fig. 46) are checked to see whether they are clogged. To do this, oil

is filled into the cylinders through oil-filling holes *12* and the oil level in the cylinders is compared with that indicated by the oil gauge glasses. If the levels are the same, the oil gauge glasses and the valves are in good order.

The insulating parts taken out of the cylinders and also the porcelain insulators are wiped with clean rags having no pile.

If the cylinder parts are in good order, the cylinder is re-assembled in reverse order. When installing the cluster contact (if it has been taken out of the cylinder), care should be taken to see that the tinned end of boss *6* (see Fig. 46) is clean.

When installing the arc-control chamber, one must check the distance of its bottom surface to the top of the cluster contact. This distance (dimension *D* in Fig. 49) must be anywhere between 10 and 15 mm.

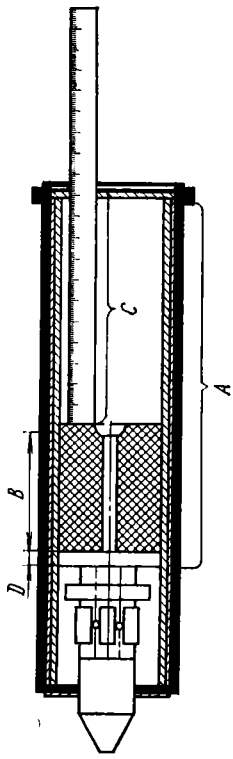


Fig. 49. Installation of arc-control chamber in MГГ-10 breaker

To accomplish this, first the height of the arc-control (dimension *B*) chamber and then the distance of the cluster contact strips to the top end of the steel cylinder (dimension *A*) are measured, the latter with a scale rule. Once the chamber is installed in the cylinder, the distance of its top plane to the top end of the cylinder (dimension *C*) is measured. The distance of the chamber to the cluster contact (dimension *D*) is determined as the difference of the measured distances, i.e.

$$D = A - (B + C)$$

If dimension *D* is not held to 10-15 mm, the height at which the chamber is placed in the cylinder (dimension *B*) needs to be changed by putting cardboard washers under

lower sleeve *3* (see Fig. 48) of phenolic resin plastic or by reducing the height of the cylinder.

The holes in upper distance sleeves *1* of phenolic resin plastic must be in line with those in the steel cylinders.

In mounting the covers with the bushing insulators, care must be taken to see that the tinned faces of the cylinders are clean. The bolts of the covers should be tightened evenly to avoid misalignment with the cylinders. At the same time the arcing contact rod must be checked for free movement (without sticking or excessive friction). It must enter the cluster contact by about 100 mm when allowed to drop by gravity from a height of some 500 mm (the distance of the top end of the rod to the top end of the bushing insulator).

Next the pot cylinders of the circuit breaker are checked for proper arrangement and installation. Their vertical position is checked with a plumb bob, and the spacing with a scale or folding rule. The centre lines of the cylinders must be spaced at 370 mm within one pole and at 300 mm for adjacent poles. Care also must be taken to see that the load-carrying contacts of the cylinders of one pole are strictly in line with one another.

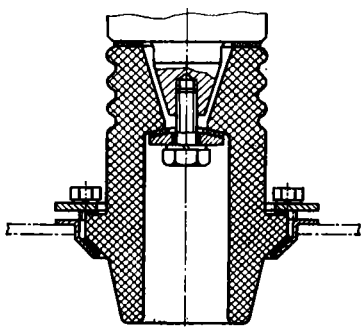


Fig. 50. Attachment of support insulator

The cylinders of each pole should also be checked for proper position with respect to rocker *2* (see Fig. 47) of the breaker mechanism. A plumb bob dropped from the midpoint between the cylinders of a pole (370 mm/2, see Fig. 43) must hit the midpoint of the insulating rod-to-rocker attachment to within 3 mm.

The cylinders together with the support insulators can be slightly shifted, if required, about the frame due to clearances provided in the holes. The support insulators are mounted (Fig. 50) so as to enable a vertical adjustment of the cylinders.

Mounting of contact system. The pre-dressed contact rods are lowered until they are abutt with the base of the cluster contact. Then the insulating rods are installed into place, along with the cross-heads and the moving load-carrying contacts, and the lower ends of the rods are attached to the circuit breaker mechanism. Next the contact rods are pulled out of the pot cylinders and secured temporarily in the cross-heads, whereupon the pot cylinders are finally aligned and secured so that the arcing contact rods taken out

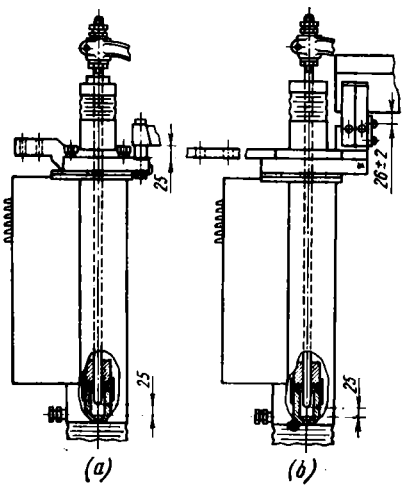


Fig. 51. Circuit breaker contacts in closed position
(*a*) 2 000-A breaker; (*b*) 3 000-A breaker

of the cylinders can fit into their respective holes in the cross-head. To prevent the contact rods from coming against the base of the cluster contact, they are fixed in the uppermost position.

Prior to adjustment, the pot cylinders of the circuit

breaker are filled with clean transformer oil and the amount of oil is checked in oil dashpots *4* (see Fig. 47) which must be about one-half full of suitable machine oil.

Adjustment of the circuit breaker complete with the operating mechanism. The adjustment is started after the circuit breaker has been mounted in place. First, the length of the

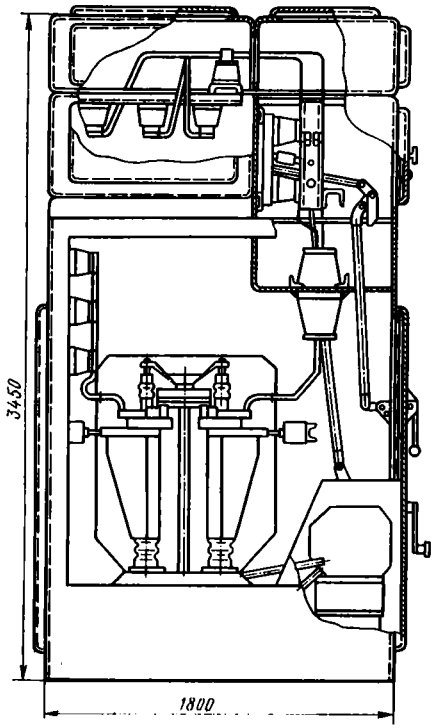


Fig. 52. Series K-XXII KRU unit with MGG-10/750 circuit breaker

tie rod coupling the circuit breaker to its operating mechanism is adjusted so as to make the circuit breaker and the operating mechanism an exact match. Both are in the closed position. One must remember that when the operating mechanism is in the closed position, roller shaft *1* (see Fig. 44) must rest on latch *2*. The circuit breaker mechanism is lo-

cked in the closed position by stops *5* (see Fig. 47). In adjusting the length of the tie rod, one must take into account that it must be screwed into its end fitting at least 25 mm deep.

Then the travel of the breaker moving contacts is checked. The jack is employed to open the unit slowly to the limit set by stops *5* which are located near oil dashpots *4*. The contact travel must be anywhere between 290 and 300 mm. The next to be adjusted are the load-carrying contacts which must be arranged as shown in Fig. 51. The proper position of the contacts is adjusted by varying the length of the tie rod. The contact rod travel in the cluster contacts is subsequently adjusted to within 90-95 mm. To determine the instant when the arcing contacts close up, use is made of a test circuit of the simplest kind incorporating a number of lamps that must light up all at a time.

МГГ-10 circuit breakers are installed in КРУ switchgear cells. Fig. 52 depicts a МГГ-10/750 circuit breaker mounted in a factory-assembled switchgear unit.

10. Mounting of МГ-10 Oil Circuit Breakers

The МГ-10 is a small-oil volume separate-pole porcelain-insulated circuit breaker rated for 10 kV. The oil serves as an arc-extinguishing medium and not as an insulation. The mounting dimensions of the circuit breaker are given in Fig. 53. The circuit breaker has a dry mass of 2 100 kg, and its pots take 55 kg of oil.

In the МГ-10 there are two current circuits (Fig. 54), *load-carrying* (contact angles *1*, blades *2*, and finger contacts *3* of the first pot, copper plates, finger contacts *5*, blades *6*, and contact angles *7* of the second pot) and *arc-control* (cover *16*, pot wall *14*, cluster contact *13*, contact rod *15* of the first pot, cross-head *4*, contact rod *10*, cluster contact *12*, pot wall *9*, and cover *8* of the second pot). In the closed position the two circuits are paralleled.

As the circuit breaker is being opened, the contacts part first in the load-carrying circuit, and then in the arc-control one. In the load-carrying circuit, first the central finger contacts and then the outer ones (extended and protect-

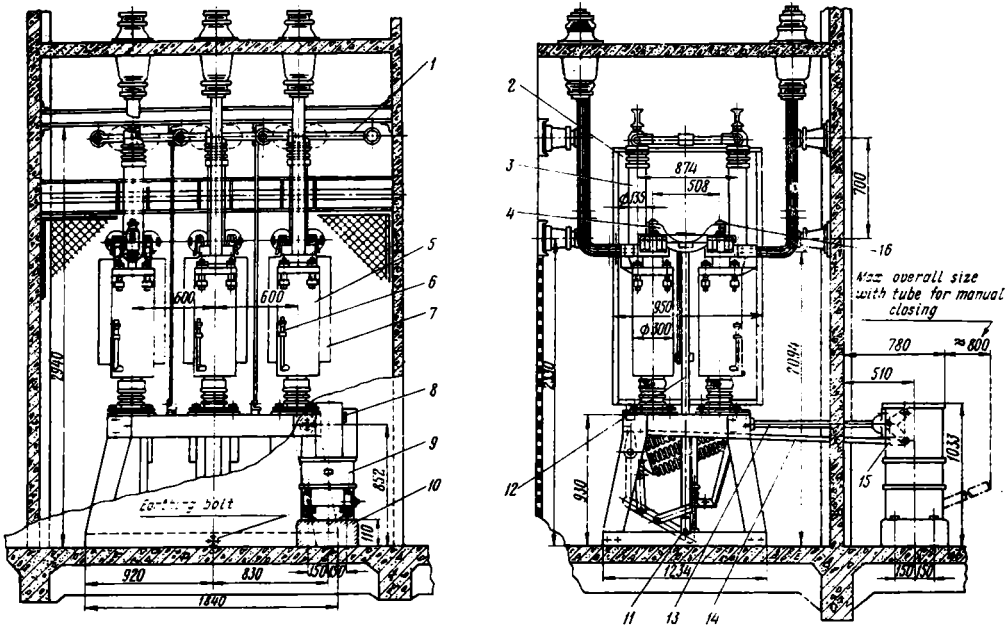


Fig. 53. МГ-10 oil circuit breaker

1—gas vent; *2*—interphase barrier; *3*—oil-baffle tubes; *4*—cross-head; *5*—pot (cylinder); *6*—oil gauge glass; *7*—in-pole barrier; *8*—hand-trip lever; *9*—ПС-31 operating mechanism; *10*—underplate; *11*—end fitting of insulating lift rod; *12*—insulating lift rod; *13*—distance tube; *14*—tubular tie rod; *15*—clevis; *16*—nut

ed against spark-wearing by kirite liners go off their blades. When the circuit breaker is closed, the contacts close up in reverse order.

The arc-control chamber of the МГ-10 circuit breaker, arranged on the side-blast principle, is a series of disks made

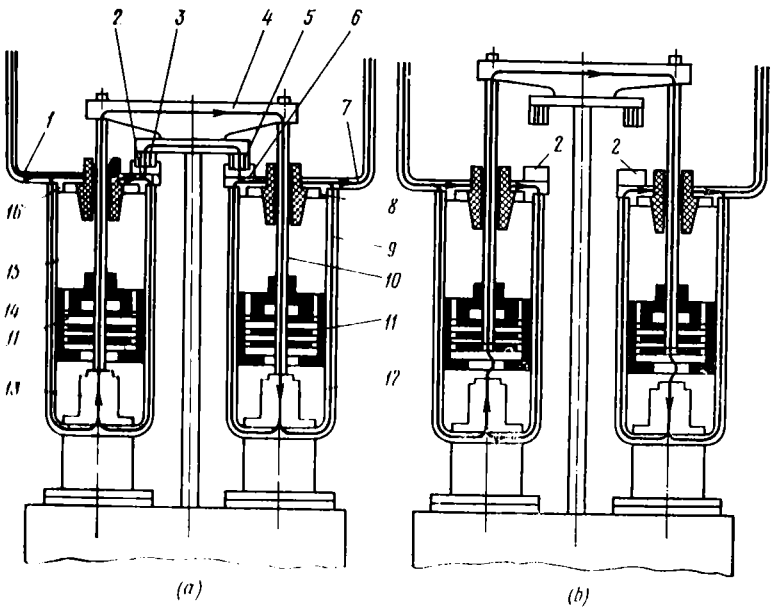


Fig. 54. Passage of current in МГ-10 circuit breaker

(*a*) in closed position; (*b*) at the point of opening; *1* and *7*—contact angles; *2* and *6* blades; *3* and *5* finger contacts; *4*—cross-head; *8* and *16*—covers; *9* and *14* pot walls; *10* and *15*—contact rods; *11*—arc-control chamber; *12* and *13*—cluster contacts

of aviation plywood. The blast is guided in the intended direction through the passages and openings formed by the assembled disks due to shaped slots in the latter. To remove the gas evolved on opening the circuit breaker and to separate the oil particles rising with the gas, use is made of an oil separator (Fig. 55) which is essentially tube *2* of phenolic resin plastic filled with porcelain balls *3* cooling the exit

gas and holding back the oil particles. The oil-baffle tube is topped with hollow porcelain insert *4* with cast-iron head *6* connecting the oil separator to a gas vent.

The circuit breaker is operated by a ПС-31 mechanism (ref. No. 9 in Fig. 53) of 675 kg mass.

The operating mechanism functions as follows (Fig. 56).

Closing. Manual closing is effected using a telescopic jack placed under the bottom face of core *9*. As the core is

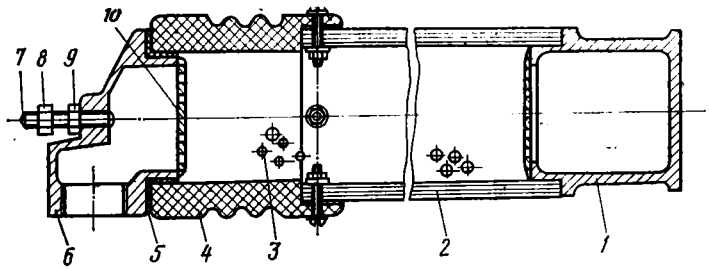


Fig. 55. Oil separator

1—base; *2*—tube of phenolic resin plastic; *3*—porcelain balls or pebbles; *4*—porcelain insert; *5*—gasket; *6*—cast-iron head; *7*—thrust bolt; *8* and *9*—lock nuts; *10*—oil baffle

raised by the jack, rod *8* comes against roller *13* and moves it upwards. The roller acts, via lever *14* and shackle *4*, on lever *2* linked to the circuit breaker mechanism. As rod *8* moves upwards, its shaft *12* shifts latch *5* to the right. At the end of the closing stroke, the latch is shifted by its spring under shaft *12*, thus locking the operating mechanism in the closed position.

Remote closing follows the same course as described above. The only difference is that the core of the operating mechanism is actuated by the magnetic field set up by the passage of current through the winding of the closing coil.

Opening. In the case of either manual or automatic, or remote opening, strip *23* goes upwards and releases roller *22* which is liable to turn clockwise under the action of the opening springs of the circuit breaker. This disturbs links *16*, *19*, and *20* of the mechanism from an equilibrium condition. As a consequence, lever *14* moves to the left, shaft *12* slips off its latch, and the circuit breaker, with its shaft coupled to the operating mechanism, is opened by the action

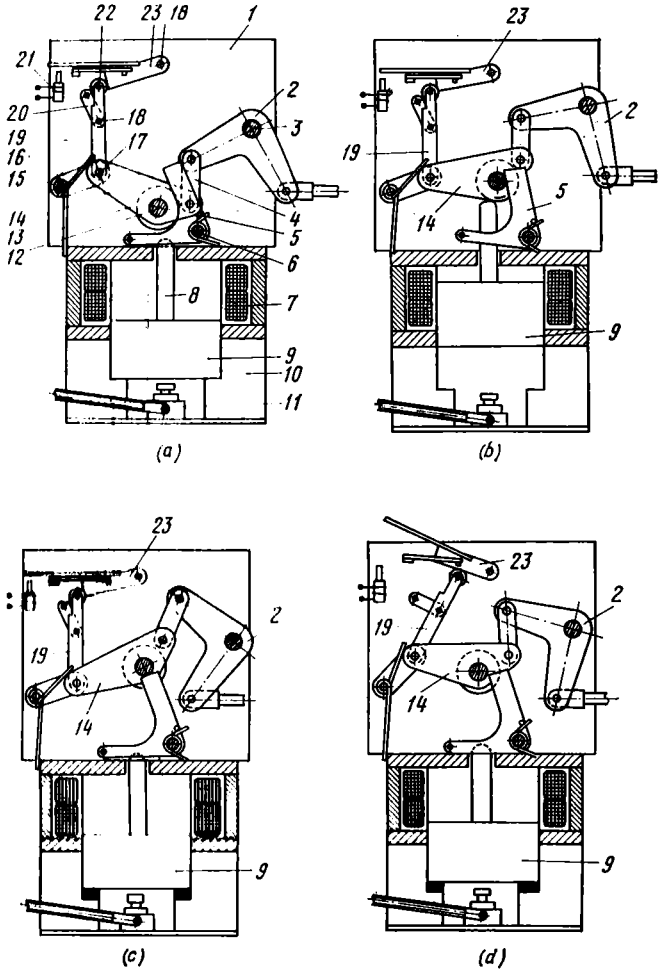


Fig. 56. IIC-31 operating mechanism. Arrangement and linkage

(*a*) open; (*b*) closing process; (c) closed; (*d*) beginning of opening stroke; *1*—housing; *2* and *14*—levers; *3*, *6*, *12*, *15*, *17*, and *18*—shafts; *4*—shackle; *5*—latch; *7* closing coil winding; *8*—rod; *9*—core; *10*—operating mechanism base; *11*—jack; *13* and *22*—rollers; *16*, *19*, and *20*—links; *21*—opening coil; *23*—strip

of the springs; the system of links *16*, *19*, and *20* regains its original position.

Mounting of the circuit breaker and operating mechanism. The circuit breaker comes from the manufacturing plant with its mechanism locked in the closed position. It shares a common crate with the oil separators and gas vent pipes removed for transportation. The same package contains a

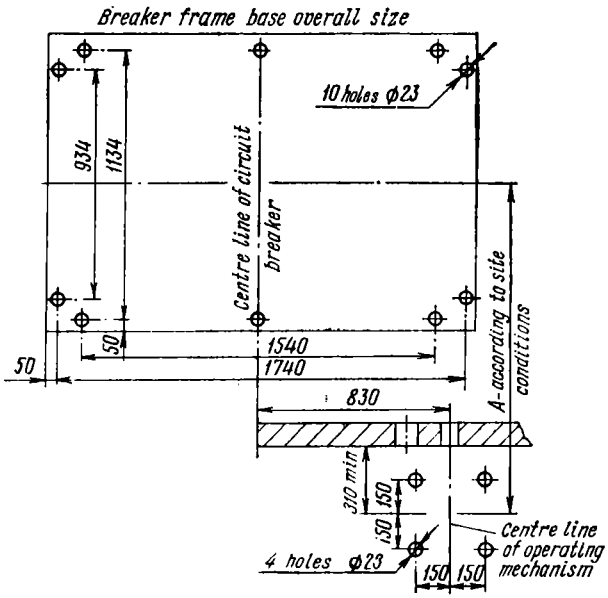


Fig. 57. Location of bolt holes in floor for МГ-10 breaker and ПС-31 operating mechanism

spanner to unscrew the cluster contact and a telescopic jack for manual closing and opening. The mechanism is locked by a shackle fastening the main shaft lever to the breaker frame.

The circuit breaker is unpacked and thoroughly inspected, with special care taken to see that the porcelain insulators are intact. At the same time the contents are checked against the packing list for missing parts.

The circuit breaker is pulled to its cell on rollers by a hand-operated or electric winch. By the time scheduled for

mounting the circuit breaker the builders should prepare anchor holes in the floor of the switchgear cell to bolt down the unit, or a foundation (if the circuit breaker is to be mounted on one). Figs 57 and 58 are layout drawings for mounting the circuit breaker and its operating mechanism.

The operating mechanism is mounted at the same time as the circuit breaker and secured to an underplate or channels with M20 bolts.

The circuit breaker is coupled to its operating mechanism (see Fig. 53) by tie rod *14* made of 1 1/4-inch pipe and pro-

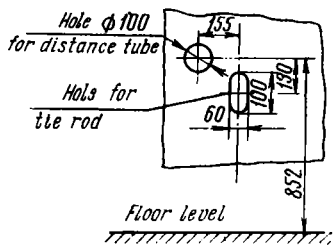


Fig. 58. Location of openings to pass distance tube and tie rod to MT 10 breaker through cell wall

vided with adjusting clevises *15*. The ends of the pipe are pre-threaded so that either of them can be screwed into the clevis end fitting at least 35 mm deep. One end of the tie rod is then connected to the lever of the breaker shaft, the other to the lever of the operating mechanism. Also, placed between the circuit breaker and its operating mechanism is distance tube *13* of 2-inch diameter, with its one end being screwed, at least 35 to 40 mm deep into the flange of the operating mechanism housing and the other bearing up against the breaker frame.

Internal inspection. After the circuit breaker and operating mechanism have been mounted in place, the telescopic jack is placed between the feet of the operating mechanism, under the centre of the core bottom face, and operated to push the unit past its closed position, thus relieving of tension the shackle that has kept the circuit breaker in the closed position. The shackle is removed and the breaker opened.

With the breaker open, nuts *15* (see Fig. 59) which secure contact (arcing) rods *12* are unscrewed and clamping bolts *14* are slackened. The arcing rods are then lowered until

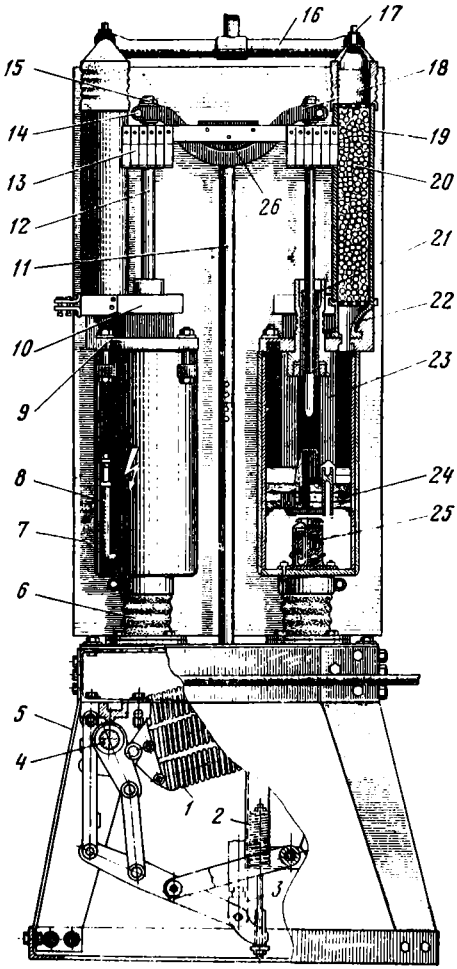


Fig. 59. МГ-10 circuit breaker design

1—opening springs; *2*—spring buffer; *3*—end fitting of insulating lift rod; *4*—breaker main shaft; *5*—frame; *6*—support insulator; *7*—insulating barrier; *8*—oil gauge glass; *9*—pot cover; *10*—fixed contact blades; *11*—insulating lift rod; *12*—contact (arcing) rod; *13*—moving load-carrying (finger) contact; *14*—coupling bolt; *15*—nut securing contact rod; *16*—gas vent pipes; *17*—thrust bolt; *18*—cross-head; *19*—oil-baffle tubes; *20*—porcelain balls or pebbles; *21*—contact rod seal; *22*—bushing; *23*—insulating members; *24*—arc-control chamber; *25*—cluster contact; *26*—current-conducting cross-bar

they come abutt with the bottom of the pot. End fitting *3* of insulating lift rod *11* is disconnected from the operating mechanism, and the insulating rod is removed together with the cross-head mounting movable load-carrying contacts (Fig. 60). The arcing rods are taken out, the pot covers removed (see Fig. 59), and arc-control chambers *24* lifted out along with insulating members *23*.

Using the spanner furnished with the breaker, the four nuts fastening cluster contact *25* in the bottom of the pot

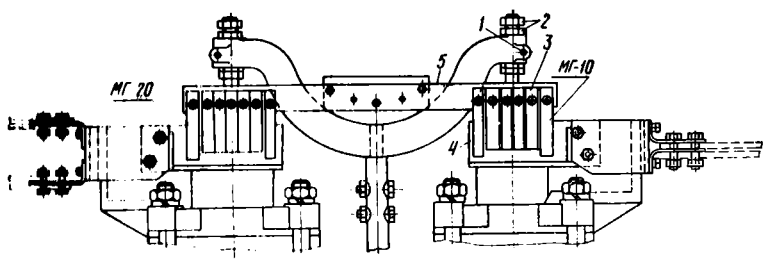


Fig. 60. Load-carrying contacts of breaker pole

1—coupling stud; *2*—nut; *3*—finger contacts; *4*—contact blade; *5*—current-conducting crossbar

are slackened, the contact is turned clockwise by hand until the slots in its base are in line with the nuts, and the contact is removed from the pot.

All the parts are collected in a suitable place where they can be inspected and wiped clean. The metal parts should be wiped with a rag soaked with petrol, and the insulating parts, with a dry rag.

In the case of an interruption in the work, the opened pots must be covered with clean rags or paper to shut out any dirt or impurities.

After internal inspection, the circuit breaker is reassembled. First the cluster contact is mounted so that it is placed precisely in the centre of the pot bottom. Next the side-blast (arc-control) chambers are installed, to be followed by the pot cover. Before the covers are bolted in place, the arcing rods should be checked to see that they are free to

pass through the bushing and the side-blast barrier and that the flexible lead located under the pot cover is fully compressed.

With the arcing rods lowered through the bushings until they are abutt with the bottoms of the pots, the insulating lift rod and cross-head are mounted, and lower end fitting *3* of the lift rod (see Fig. 59) is attached to the circuit breaker mechanism.

The arcing rods are then lifted from the pots, secured in the cross-head, and fixed in the uppermost position.

Adjustment of the circuit breaker and operating mechanism for joint operation. This is done by varying the length of

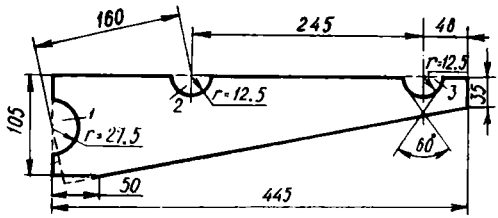


Fig. 61. Template for checking МГ-10 circuit breaker mechanism

tie rod *14* (see Fig. 53) by means of its clevis *15*. For adjustment purposes the circuit breaker is opened and closed with the aid of a jack. Concurrently with tie-rod length adjustment the length of insulating lift rod *11* is also adjusted. This is done by screwing end fitting *3* in or out (see Fig. 59) so that in the closed position the shafts of the breaker mechanism are brought into a relative arrangement corresponding to a template. In other words, with the template placed against the shafts, points *1*, *2* and *3* (Fig. 61) should coincide with points *1*, *2* and *3* of the breaker mechanism (Fig. 62). The tolerance ("underclosure") for the middle shaft is 3 mm.

Next the travel of the cross-head is adjusted so that it is anywhere between 440 and 410 mm (420^{+20}_{-10} mm). The oil dashpots of the breaker are filled with oil two-thirds full.

Then comes the adjustment of the breaker contacts — an extremely important and responsible operation. For

this adjustment, the circuit breaker is opened, and the protective grease is removed from its contacts. Then the circuit breaker is reclosed by means of its operating mechanism (at normal voltage) and the distances from the tops of blade contacts *4* to current-conducting cross-bars *5* (see Fig. 60)

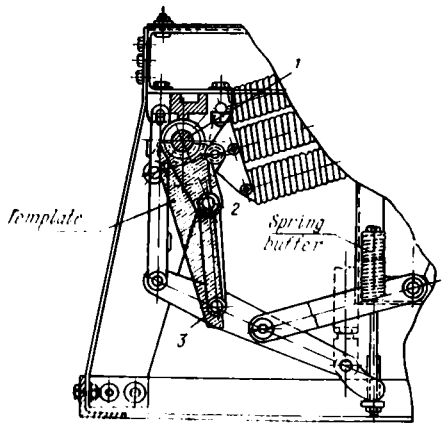


Fig. 62. Checking of MT-10 circuit breaker mechanism

are checked. They should be 22 ± 1.5 mm; otherwise end fitting *3* (see Fig. 59) on the lift rod should be screwed in or out, as the case may be.

When the distances measured on the pots of any one pole differ by more than 3 mm, the respective tank should be lifted or lowered by means of washers placed under the base of the support insulators.

Each pole is then checked to see that on a closing stroke all the finger contacts touch the blade contacts simultaneously. They may be considered to do so if, when the breaker is slowly closed by means of a jack, the cross-head moves through not more than 5 mm between the moments when the first and last fingers touch their blade contacts.

The pressure of the finger contacts on the blade contacts is next measured with a dynamometer (Fig. 63) and should be 14 ± 1 kg. The pressure of one finger contact in each pair should be measured. If the pressure is insufficient, the contact springs are tightened.

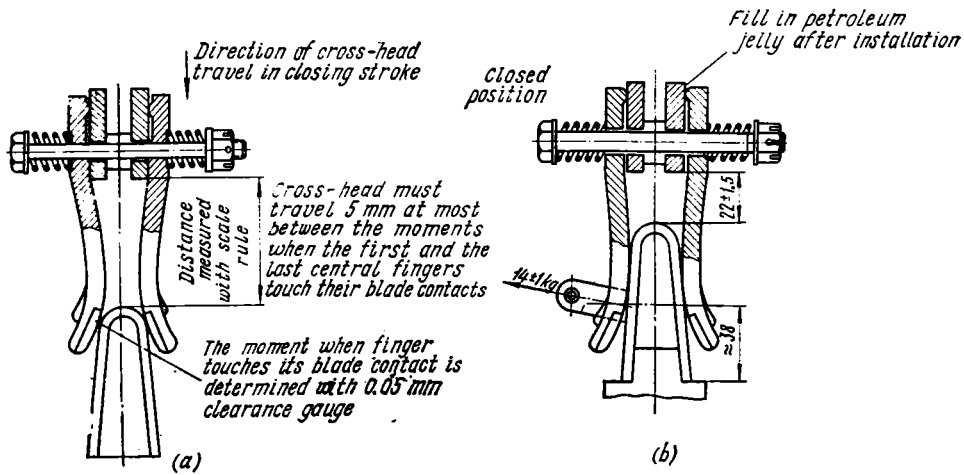

Direction of cross-head travel in closing stroke
Distance measured with scale rule
Cross-head must travel 5 mm at most between the moments when the first and the last central fingers touch their blade contacts
The moment when finger touches its blade contact is determined with 0.05 mm clearance gauge
(a)
Fill in petroleum jelly after installation
closed position
22±1,5
14±1,5
≈38
(b)

Fig. 63. Adjustment of breaker load-carrying contacts
(a) at the beginning of closing stroke; (b) in closed position

After the adjustment, the contact surfaces of the fingers and blades as well as all external current-carrying parts are wiped with a clean cloth moistened with petrol and are given a thin coat of petroleum jelly. The arcing rods are then secured in the cross-head so that, when the circuit breaker is closed by its solenoid operating mechanism at the rated voltage, the arcing rods stop within 20 or 25 mm of the cluster contact base.

Mounting of oil-baffle tubes and gas vent pipes. The oil-baffle tubes *3* are seated on gaskets of rubberized composition or asbestos, and the gas vent pipes *1* are then set up (see Fig. 53). Next thrust bolts *7* (see Fig. 55) are unscrewed from the head of the oil-baffle tubes until they come against the beams in the upper part of the cell and then their lock nuts are tightened. The thrust bolts should be tightened with care so as not to misalign the oil-baffle tubes and the breaker pots.

The interphase barriers are attached to the upper part of the breaker frame and to the channels against which the thrust bolts of the oil-baffle tubes are forced. The in-pole barriers are installed.

When breakers are installed not near one another, two-inch gas vent piping is run directly outdoors. When circuit breakers are mounted in groups, the gas vents are connected by means of two-inch pipes to a common four-inch gas manifold. In the former case, the pipe ends must be fitted with either a flap valve or by easily-replaceable parchment membranes. The outlets of the gas vent pipes must be turned downward.

11. Mounting of Instrument Current Transformers

Design and connection. The ratio between the currents in and the numbers of turns on the windings of a current transformer (Fig. 64) should be written as

$$\frac{I_1}{I_2} = \frac{w_2}{w_1} = r$$

where I_1 is the primary current, I_2 is the secondary current, w_1 and w_2 are the numbers of turns on the primary and the secondary windings, respectively, and r is the true ratio of the transformer.

Current transformers are employed in switchgear installations with the aim:

to extend the range of ordinarily used instruments having current windings (ammeters, wattmeters, meters);

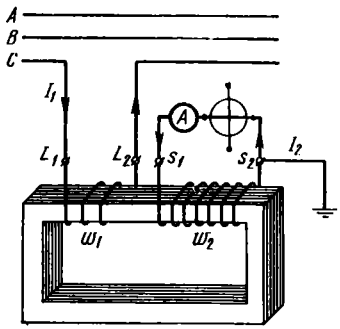


Fig. 64. Winding connections of current transformer

to energize the current windings of relays and, in specific instances, the opening coils of the operating mechanisms of power switches;

to isolate the secondary circuits from the primary ones.

The latter function is of particular importance in ensuring the safety of attending personnel. The secondary windings and the casing of a current transformer are normally connected to earth.

The windings of current transformers may be connected in different ways (Fig. 65). If, for instance, all the three phase currents are to be checked, the windings of three transformers are connected in a star or delta. These circuit designs are also specific to some types of relay protection.

In insulated-neutral systems, the windings of two transformers are connected in a star or in a circuit enabling the difference of two phase currents to be taken. With relay protection against earth fault, a circuit enabling the sum of the three phase currents to be taken is employed.

If the maximum possible power is to be had from the secondaries of two transformers in one phase, the windings are connected in series. Parallel connection of the same windings allows an increase in the secondary current.

To illustrate the design of bushing current transformers most commonly used in indoor switchgear, considered below

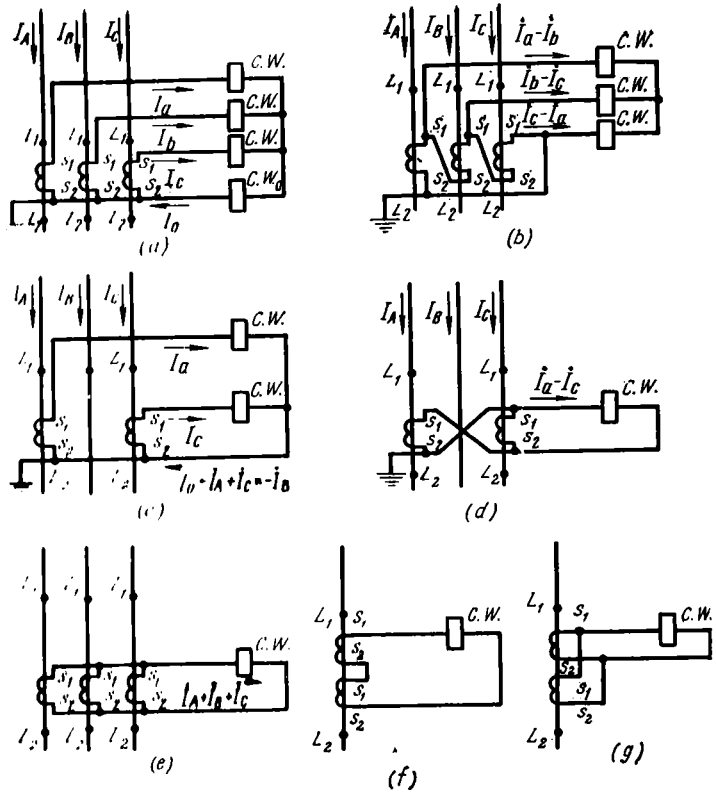


Fig. 65. Connections of current transformers

(a) star-connected windings of three transformers; (b) delta-connected windings of three transformers; (c) star-connected windings of two transformers; (d) circuit to take difference of two phase currents; (e) circuit to take sum of three currents; (f) two series-connected windings of one phase; (g) two parallel-connected windings of one phase

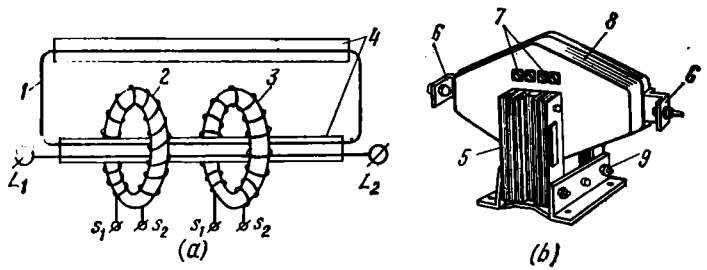


Fig. 66. TIIJI transformer

(a) design; (b) general view

is a ТПЛ bushing current transformer with moulded epoxy insulation. As is seen from Fig. 66*a*, transformer primary *1* encapsulated in insulation *4* passes through cores *2* and *3* carrying the secondaries. Leads L_1 and L_2 ("L" stands for "line") serve to hook the transformer into the primary circuit. Terminals S_1 and S_2 ("S" stands for "secondary") are to connect the secondary circuits with measuring instruments, relays, etc.

The transformer (Fig. 66*b*) has moulded epoxy casing *8* accommodating the windings. The casing is fixed, through

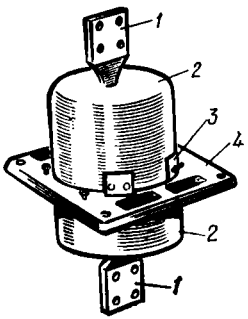


Fig. 67. ТПОЛ moulded current transformer
1—primary terminals; *2*—moulded casing; *3*—secondary terminals; *4*—flange

yoke *5*, to steel angle (lug) *9*. Bus *6* of the primary terminates in two binding posts marked L_1 and L_2. Terminals *7* of the secondary are arranged on the casing and marked S_1 and S_2.

A ТПОЛ transformer (Fig. 67) is arranged on the same principle with the difference that its primary has a single turn — a bar connecting primary circuit buses at both ends.

A ТПШЛ transformer also lacks the primary which is substituted by a busbar passed through the unit at the time of installation.

For most transformers the rated secondary current is 5 A. This current will flow through the secondary if the current in the primary circuit becomes equal to the rating of a given transformer.

Among the specifications of a particular current transformer is the accuracy class of the secondary. The accuracy class gives an estimate of the measurement errors introduced by the current transformer.

Some of the current transformer types and their specifications are presented in Table 8.

Table 8

Current Transformer Specifications

Type designation	Rated primary current, A	Core designation		Mass, kg
		first core	second core	
TIIJI 10-P	5-400	P	—	9
TIIJI 10 0.5/P	5-400	0.5	P	16.5
TIIJI 10 P/P	5-400	P	P	17
TIIJIY 10 0.5/P	10-100	0.5	P	16.5
TIIOJI 10 P/P	600-1500	P	P	17
TIIOJI 10-0.5/P	600-1500	0.5	P	17

Note. The following designations are used: Y — increased strength; 10 — voltage rating, kV; 0.5/P — core designation and accuracy class of secondary (P — 0.5 accuracy rating).

Checking of current transformers prior to mounting. A transformer received for mounting should be checked to see that its components are intact, the lead markings and the nameplate are available.

In addition to a visual inspection, all current transformers must be put through a number of tests carried out in a workshop or by an adjusting crew. The continuity of the secondary can be checked by means of the circuit given in Fig. 68*a*. If there is no break in the winding, the pointer of the megohmmeter tester will deflect across the entire scale when the handle is cranked. When a break exists in the winding, the pointer will remain at zero. The secondary can also be checked for continuity with a compact Wheatstone bridge. A break, if any, will then be indicated by an infinite resistance registered by the instrument.

The insulation resistance is measured by the use of the schemes given in Figs 68*b* and *c*. The insulation resistance is not subject to standards, but it should be at least 50 to 100 MΩ for the primary and at least 10 to 25 MΩ for the secondaries when measured by a megohmmeter rated for 1 000 to 2 500 V.

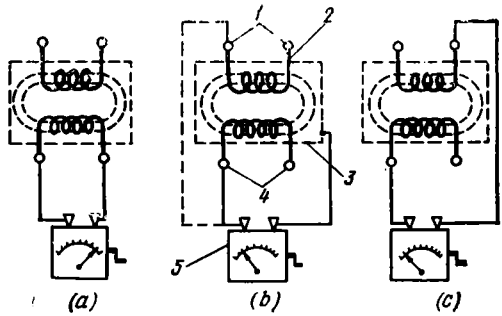


Fig. 68. Current transformer test circuits

(*a*) for continuity check on secondary; (*b*) for measuring insulation resistance relative to earth (dashed line for primary and solid line for secondary); (*c*) same, between primary and secondary; *1*—primary terminals; *2*—primary; *3*—transformer casing; *4*—secondary terminals; *5*—megohmmeter

Current transformers are finally subjected to a high-voltage test during which their secondary windings must withstand a test voltage of 2 000 V and primary windings, the voltage specified in the applicable standard, both at power frequency for one minute.

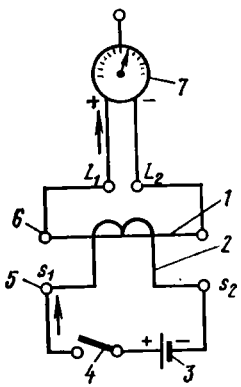


Fig. 69. Winding polarity test circuit

1—primary; *2*—secondary; *3*—dry cell; *4*—switch; *5* and *6*—winding terminals; *7*—galvanometer

The polarity of a current-transformer windings is determined by means of the test circuit shown in Fig. 69. The circuit employs a galvanometer with the midmost zero mark

and a dry cell. A portable 6-to 12-V storage battery will be more convenient.

If the polarity is correct, the instrument pointer should deflect to the right on closing the circuit; deflection of the pointer to the left indicates that the polarity of the secon-

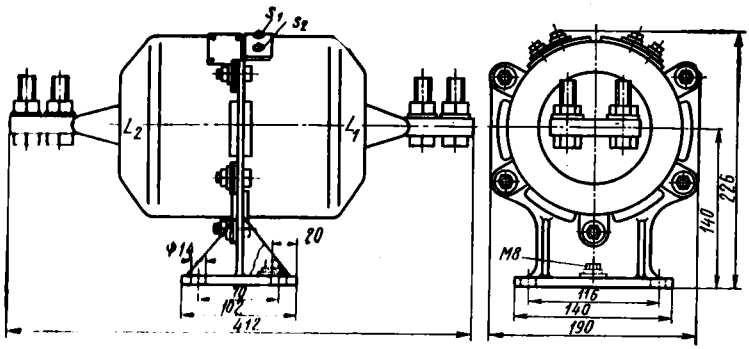


Fig. 70. ТПОЛ-10 transformer with mounting lug

dary is the reverse of that specified by the manufacturer and that its ends must be reversed or its terminal markings changed.

Mounting. In cubicle-type switchgear structures for indoor use, instrument current transformers are mounted on steelwork of angles, on steel plates, or on reinforced concrete slabs.

Figure 70 shows the mounting dimensions of a ТПОЛ-10 transformer provided with a lug serving to fasten the unit to the supporting metalwork with four bolts.

A transformer of the same type with a mounting flange is depicted in Fig. 71. The flange of the unit is fastened, with four bolts, to steel angles or to reinforced concrete slabs in openings provided for passage through the walls and floors of a switchgear structure.

In factory-assembled switchgear installations, current transformers are secured to the metalwork of a КРУ unit.

The terminals of current transformers should be so arranged that the incoming power buses are taken to the terminals marked L_1 and the outgoing buses are connected to the ter-

minals marked L_2. Otherwise, the polarity markings of the secondary windings, S_1 and S_2, will have to be reversed.

Once a transformer is fixed in position, the earth connections should be completed for its secondary winding(s) and

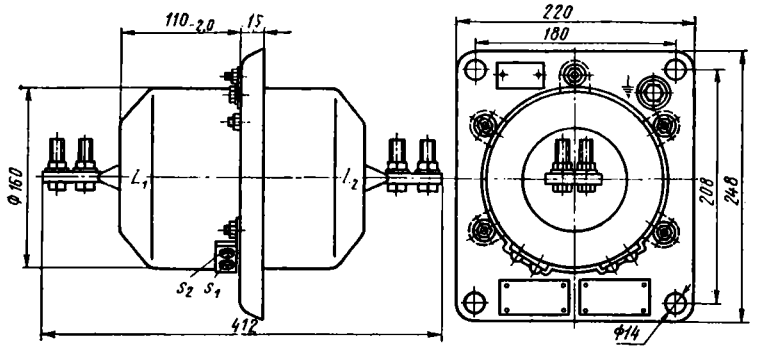


Fig. 71. ТПОЛ-10 transformer with mounting flange

metal base in order to provide for the safety of attending personnel.

If measuring instruments, relays, etc. are not connected to the terminals of the secondaries, they must be short-circuited to preclude an unsafe voltage build-up across the terminals and the circuits connected to them, and also to safeguard the transformer cores against overheat.

12. Mounting of Instrument Voltage Transformers

Design and connection. The voltage (turns) ratio for a voltage transformer (Fig. 72) will be given by

$$\frac{V_1}{V_2} = \frac{w_1}{w_2} = r_v$$

where V_1 is the primary voltage; V_2 is the secondary voltage; w_1 and w_2 are the numbers of turns on the primary and the secondary windings, respectively; r_v is the transformation ratio of the voltage transformer.

In switchgear, voltage transformers perform the same func-

tions as current transformers, yet as applied to the measuring instruments and relays that have potential windings (voltmeters, wattmeters, voltage relays, etc).

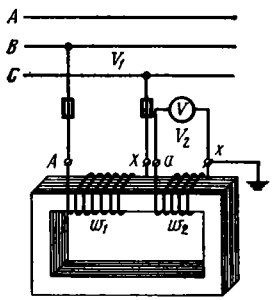


Fig. 72. Winding connections of voltage transformer

Some of the instrument voltage transformer types used in indoor switchgear are presented in Table 9, and their mounting dimensions in Figs 73 and 74. The winding connections of voltage transformers are diagrammed in Figs 75 and 76.

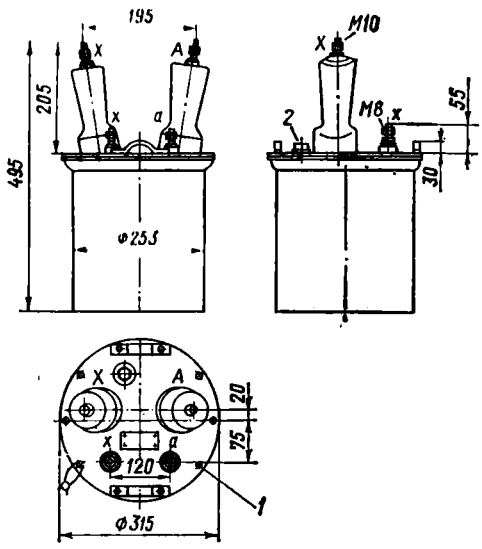


Fig. 73. HOM-10 voltage transformer
1—earthing bolt; *2*—oil-filler plug

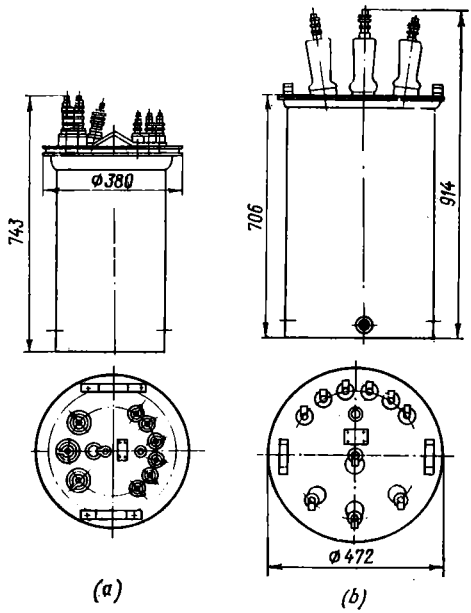


Fig. 74. Voltage transformers
(*a*) НТМП-6; (*b*) НТМИ-10

As is seen from Fig. 75*a*, three single-phase voltage transformers can be star-connected, with the neutral point of the windings available for connection to earth. This circuit

Table 9

Types and Mass of Voltage Transformers

Type designation	Total mass, kg	Mass of oil, kg	Type designation	Total mass, kg	Mass of oil, kg
НОМ-6	23	4.7	НТМК-10	100	27
НОМ-10	36	7.5	НТМИ-6	105	32
НТМК-6	47.5	15	НТМИ-10	190	70

Note. The following designations are used: Н – voltage transformer; О – single-phase; М – oil-immersed; Т – three-phase; К – compensating winding; И – insulated neutral; 6 and 10 – kV ratings.

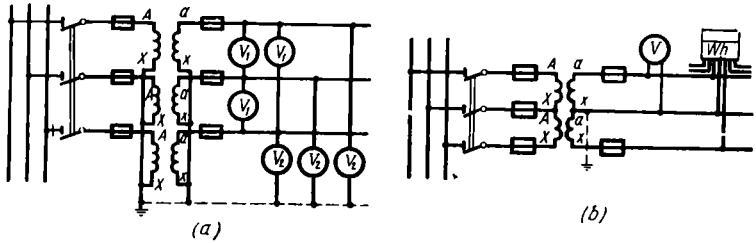


Fig. 75. Connections of single-phase voltage transformers

(*a*) star connection of three single-phase transformers; (*b*) open-delta connection of two single-phase transformers

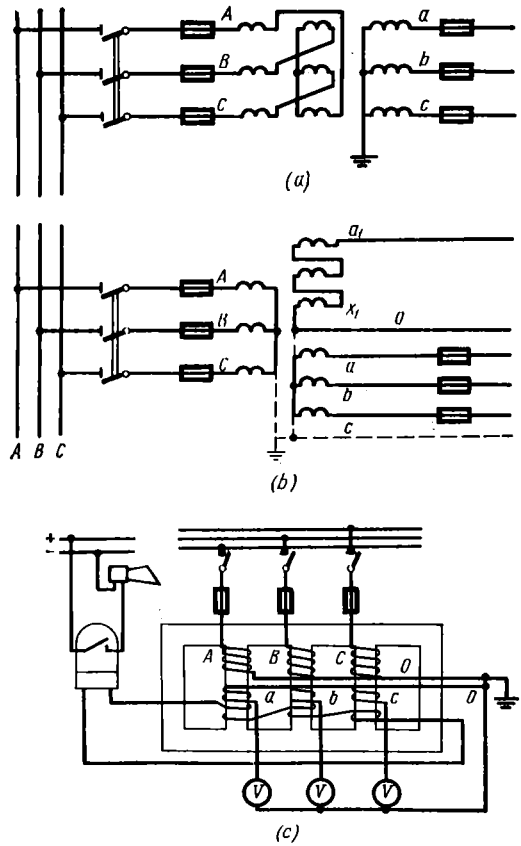


Fig. 76. Connections of three-phase voltage transformers

(*a*) НТМК transformer; (*b*) НТМИ transformer; (c) connection of instruments and relays into secondary circuits of НТМИ transformer

arrangement is employed if both the phase-to-phase and the phase voltages are to be applied to measuring instruments and relays. The condition of a network insulation can also be checked using this circuit. If the insulation is in good condition, voltmeters V_2 will register the phase voltage. With one of the three phases shorted out, the voltmeter of the faulty phase will read zero voltage, and the voltmeters in the unaffected phases will read the phase-to-phase voltage in a system with the unearthed neutral or the phase voltage in a system with the solidly earthed neutral.

In a three-phase electrical system, the windings of two single-phase transformers may be open-delta connected (Fig. 75*b*). This circuit arrangement is used if only the phase-to-phase voltages are to be applied to the instruments and relays involved.

The winding connections of voltage transformers of the НТМК and НТМИ types and the connection of measuring instruments and relays, for the purpose of insulation test, into the secondary windings of an НТМИ transformer are diagrammed in Fig. 76.

Voltage transformer inspection prior to mounting. Voltage transformers are inspected visually for broken porcelain bushings and cemented joints, for mechanical injury to the tank, and for oil leakage between the cover and tank and from under the bushing flanges. In addition, they are checked for oil level, the condition of the oil gauge, and the presence of the nameplate.

The electrical checks of voltage transformers are similar to those of current transformers and involve measurements of insulation resistance, determination of the polarity of the high-voltage and low-voltage windings, and the ratio.

In addition, since voltage transformers are of the oil-immersed type, oil samples are taken for dielectric strength and acidity tests.

The insulation of a voltage transformer is checked with a 1 000 to 2 500-V megohmmeter for the insulation resistance of the high-voltage and the low-voltage windings relative to the tank and to each other.

The requirements which the insulation in voltage transformers must satisfy are the same as those for current transformers.

To assess the general condition of the turn-to-turn insulation and iron parts, voltage transformers are tested at power frequency under the rated voltage (V_r) and under a voltage 1.3 times as high ($1.3V_r$), and the respective no-load currents are measured. The voltage is applied to the secondary. The increased voltage is impressed on the transformer for one minute. The current readings taken at different voltages (V) are compared with the manufacturer's test records or with test results available for similar voltage transformers.

If the insulation fails to meet standard requirements, the transformer should be dried out prior to high-voltage testing.

Voltage transformers can be dried out by means of short-circuit currents, in a drying oven, or by the iron-loss method with the transformer left in its tank emptied of all oil.

During the drying process, the bottom and top openings of the tank should be left open to allow the vapour to escape, and the high and low voltage windings should be shorted and earthed.

To pass a final judgement on the insulation condition, voltage transformers are subjected to a high-voltage test, as are current transformers.

Terminal polarity is checked in the same way as with current transformers. A d-c voltage is applied to the high-voltage winding and a galvanometer is connected in the low-voltage winding.

Three phase voltage transformers are checked for polarity by connecting a source of voltage to the high-voltage terminals in turn: first, say, to C and B, and the instrument to the low voltage terminals c and b; then to A and B, and to a and b, etc. If in all three cases the instrument pointer swings to the right, the leads are marked correctly. Otherwise the markings should be changed.

Mounting of voltage transformers. The mounting of voltage transformers involves three fundamental operations:

(1) placing of a metal support;

(2) lifting and setting of the voltage transformer on the support;

(3) earthing.

Metal supports for voltage transformers differ widely in construction. Fig. 77*a* shows a metal support for an НТМИ-10

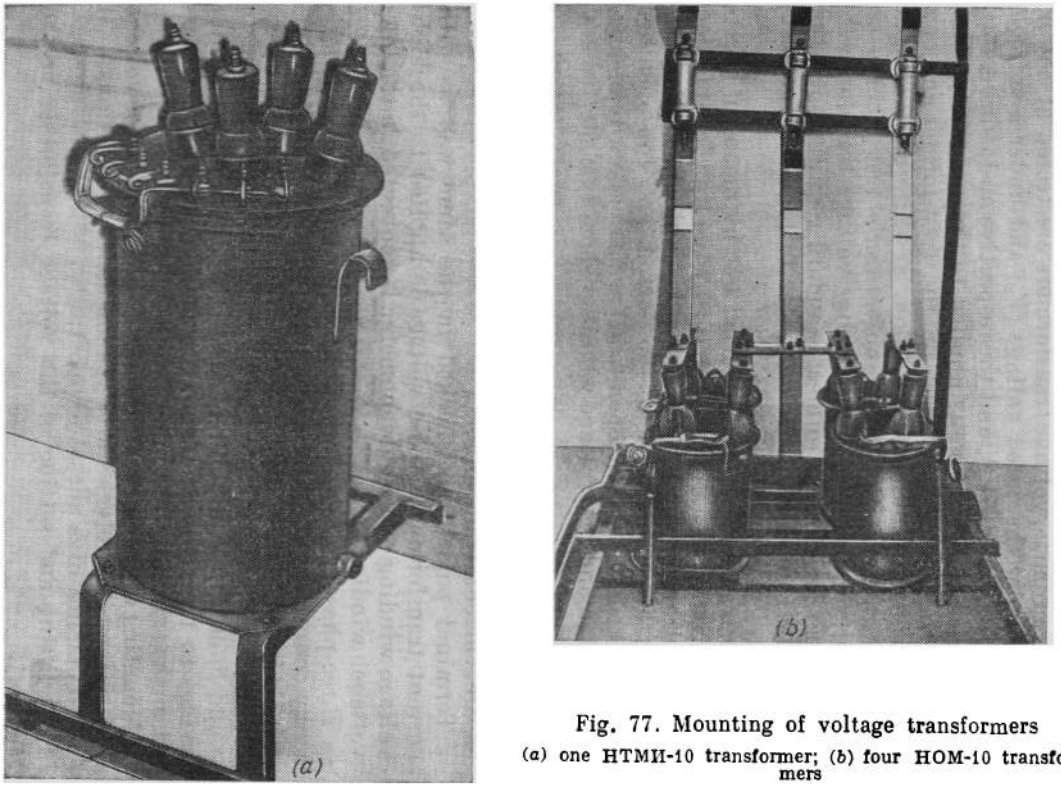


Fig. 77. Mounting of voltage transformers
(*a*) one НТМИ-10 transformer; (*b*) four НОМ-10 transformers

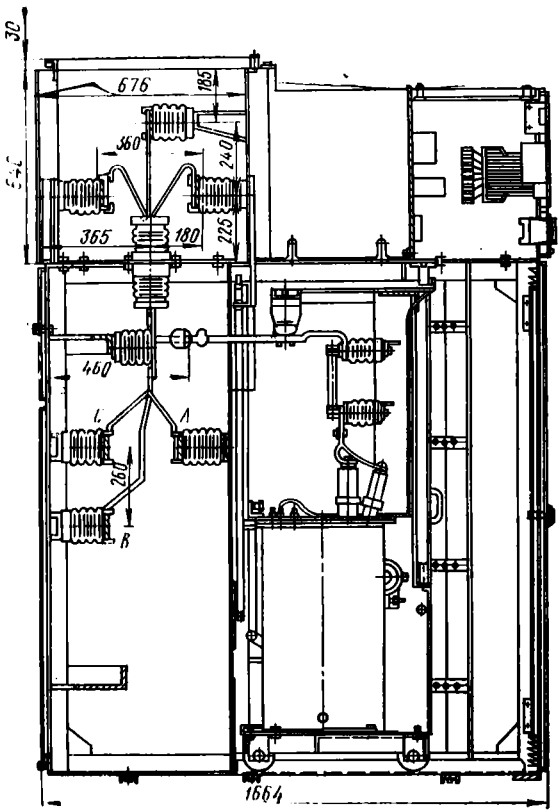


Fig. 78. КРУ unit with НТМИ-10 transformer and ПКТ fuses

voltage transformer made from steel angles and placed directly on the cell floor. Fig. 77*b* exemplifies installation of four НОМ-10 voltage transformers on angle metal supports in a cubicle-type switchgear compartment. Voltage transformers are usually lifted in position by hand using a block or hoist. During mounting, their high-voltage terminal should be shorted and earthed, and their low-voltage terminals should be disconnected from wires, as any accidental or unintentional contact of these wires with a live lighting or

power circuit will cause a high voltage to appear across the high-voltage terminals. Voltage transformers should be set up so that their oil drains and oil-level gauges face the aisle.

When mounting three-phase voltage transformers, buses should be connected to the transformer terminals with regard to the generally accepted phase sequence pattern. With a single-phase transformer, the terminal marked *X* should be earthed. When three single-phase voltage transformers are mounted in a bank, all the *X*-marked terminals should be made common by a bus and earthed. When two voltage transformers are mounted and open-delta connected, the operating phase on the low voltage side should be earthed if it is required by the design. Each voltage transformer tank must be connected to the earthing bus by an individual busbar.

In modern switchgear structures, built up from a number of КРУ cells, transformers are mounted on roll-out trucks housed in factory-assembled units (Fig. 78).

Prior to applying the voltage to a transformer, the pressboard washer should be removed from under the oil-hole bolt to provide communication with the ambient atmosphere.

13. Mounting of High-Voltage Fuses

Design and types. Indoor switchgear installations use ПК fuses (the letter П standing for "fuse", and the letter К, "quartz-sand filled") for power circuit protection, and ПКТ fuses (Т meaning "transformer") for voltage transformer protection.

The general view of a ПК fuse is depicted in Fig. 79*a*. The case (Fig. 79*b*) of the fuse is a porcelain tube with ferrules *9*. The tube accommodates fuse links *10* made of silver-plated copper wire and soldered to the end faces of the ferrules. In fuses rated for currents up to 7.5 A, the fuse links are wound on a ceramic core. The tube is filled with quartz sand. The ferrules are closed by soldered covers *6*.

The central portion of the case is threaded with an indicating steel link coupled to blown-fuse indicator *8*. Once the link has melted, a spiral spring will push out an armature of the blown-fuse indicator to indicate that the fuse has blown.

Tin balls 7 located on the fuse links promote the melting of the latter and preclude the fuse from being heated by the passage of overload current. Fuses rated for heavy currents use twin cases.

The difference between ПКТ fuses designed to protect instrument voltage transformers and ПК fuses is that the

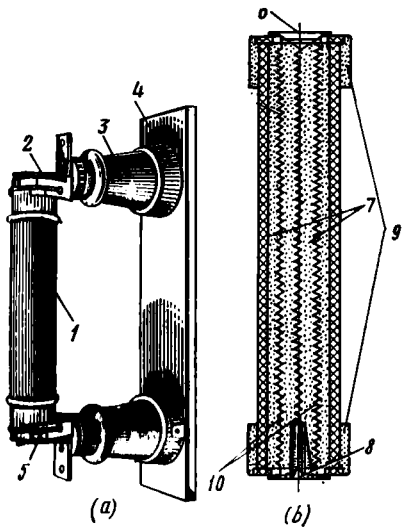


Fig. 79. ПК fuse

(*a*) general view; (*b*) fuse case (section); *1*—porcelain tube; *2*—locator; *3*—support insulator; *4*—flange; *5*—lock; *6*—cover of brass ferrule; *7*—tin balls; *8*—fuse-blown indicator; *9*—brass ferrules; *10*—fuse links

former have no blown-fuse indicators. Their fuse links are wound on a ceramic core, as with ПК cases rated for currents up to 7.5 A.

Initial inspection of fuses. The porcelain parts of fuse bases must satisfy the same requirements as support insulators.

The clip jaws must be resilient and clamp the fuse case all the way round the circumference. The fuse case should be hermetically sealed. The quartz-sand filling must be sufficiently compact; when the case is shaken, no sound of the sand moving in it should be heard.

In the case of IIK fuses the blown-fuse indicator should also be checked by pressing its armature. If the indicator is good, the armature will deflect a little and swing back.

Fuse links must also be checked for continuity with a megohmmeter in both IIK and IIKT cases. Fuse cases are inspected for matching the contact bases in current rating.

Mounting. When mounted on metalwork, the fuses of each pole are fastened with M12 bolts 50 to 55 mm long.

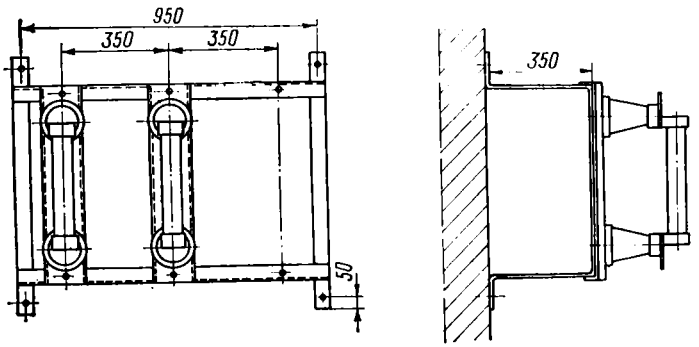


Fig. 80. IIK fuse block

Each pole is plumbed. Joint alignment of the three poles is accomplished using a batten and a level. To earth the base of each pole, reliable electric contact must be provided between the latter and the metalwork.

If fuses are to be fixed directly on a brickwork or concrete wall, it is unadvisable to mount the fuses of each pole separately. The generally followed practice is to mount the fuses on a common fuse block (Fig. 80) fabricated from steel angles and strips in a workshop.

An assembled fuse block is mounted in the ordinary way. It is secured to supports over 100 mm thick with anchor studs and also with selflocking or gun-driven dowels. To mount a fuse block on thinner supports, use is made of through bolts. The fuse block is lifted in position with tackle blocks or a winch and a block and plumbed and levelled before fixing it finally.

With the fuse cases in place, one should check to see that their ferrules enter the fuse clips without misalign-

ment. The tubes of ПК fuses should be arranged so that the blown fuse indicators face downward. One must also make sure that the cases are precluded from shifting lengthwise by locators *2* (see Fig. 79) and firmly fixed in the fuse clips by locks *5* (of ПК fuses).

Departures, if any, from the above requirements must be eliminated in the course of mounting by shifting a little the bases and insulators or by bending the fuse clips, locators, locks, and other fasteners in a somewhat different way.

14. Mounting of Cast-in-Concrete Reactors

Design. Indoor switchgear installations employ cast-in-concrete reactors made up of concentric turns of stranded aluminum wire which are grouted in to form concrete columns arranged on a radius round the centre. The wire is insulated by applying several coats of cable paper wrapped up in a cotton braiding.

At the instant a fault occurs the reactor restricts, due to its inductive reactance, the short-circuit current thus reducing the dynamic and thermal effect produced on the installation and its specific units. Concurrently, the reactor maintains an adequate voltage across the station buses at the time of a short circuit on the outgoing side.

Reactors are available for vertical, horizontal, or stepwise installation (Fig. 81). Each coil is appropriately designated *T* — top, *M* — middle, *B* — bottom, *H* — horizontal, *HM* — horizontal middle. The middle and the horizontal middle coils are wound in the opposite direction to the other two coils of a three-phase reactor bank. This results in the most favourable distribution of the forces set up by a short circuit in the concrete and insulators.

The main dimensions of some РБА cast-in-concrete reactors are presented in Fig. 82 and Table 10.

In addition to РБА reactors, available in this country are twin reactors of the РБАС type, low-loss reactors of the РБАМ type, and low-loss twin reactors of the РБАСМ type.

Inspection of cast-in-concrete reactors prior to installation. First the concrete columns are examined for possible cracks

Table 10

Main Dimensions and Mass of Some РБА Cast-in-Concrete Reactors

Type designation	Dimensions			Mass per phase, kg	Number of columns
	D_c	D_{ins}	H_{ph}		
РБА-6-600-4	1010	715	600	470	8
РБА-6-1000-10	1330	995	690	850	10
РБА-6-3000-12	1480	1005	690	1450	10
РБА-10-4000-12	1750	1175	720	2050	12

Notes: 1. The last two types are for horizontal installation only.
2. The following designations are used: Р — reactor; Б — cast-in-concrete; А — aluminum-wire coil; 6, 10 — kV rating; the last numerals, 4, 10, and 12 — inductive reactance.

and chipped spots, the reactor windings for deformed turns, the insulation for damage. Furthermore, there should be no foreign objects between the turns, and the protective var-

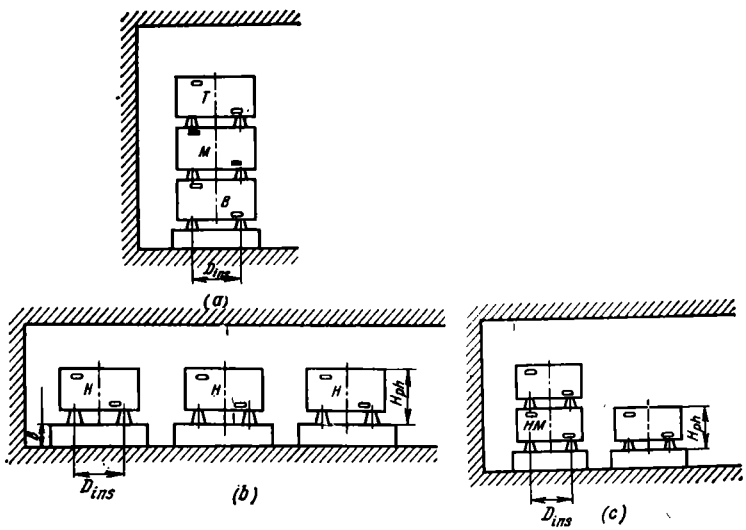


Fig. 81. Three-phase reactor bank

a) vertical installation; (*b*) horizontal installation; (c) stepwise installation

nish coating of the concrete columns should not be damaged. Also, it is important to make sure that the bolts are reliably embedded in the concrete.

Damaged reactor columns may be repaired in workshops or, if necessary, directly on the installation site. For this

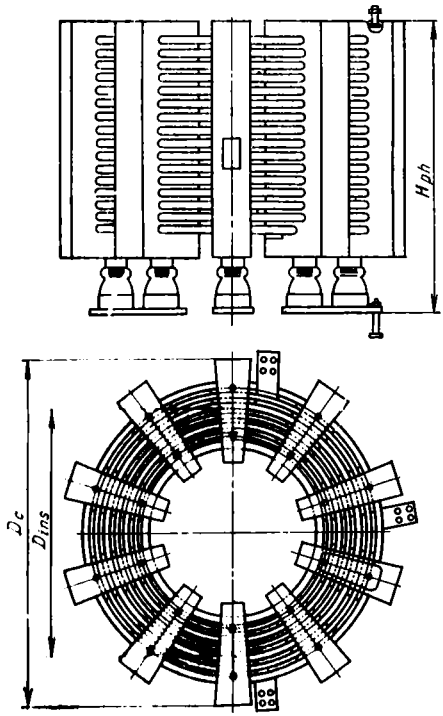


Fig. 82. One phase of reactor bank

purpose shuttering made from smooth-planed boards lightly coated with petroleum jelly or grease on the inside is put on the damaged column to be repaired.

The concrete used for the repair consists of one part of Grade 400 to 600 cement, one part of washed and dried quartz sand, one part of washed gravel (mainly consisting of granite) having a grain size of up to 5 mm, and 40 to

60 per cent of water by cement weight. This concrete has a setting time of 48 hours, after which the shuttering may be removed. Full design strength is reached 25 to 30 days after the concrete has been placed, after which time the reactor must always be dried out and baked.

Deformed turns, if any, should be carefully straightened and their damaged insulation restored with a herringbone or tafetta tape serving impregnated with phenol-formaldehyde varnish.

The reactor post insulators should meet the usual requirements for post insulators.

The insulation resistance of the reactor is measured between the winding and earth with a 1 000- to 2 500-V megohmmeter. To fully assess the condition of the reactor insulation, the insulation resistance between the phase coils is measured. In either case the insulation resistance must be at least 50 to 100 MΩ. Otherwise, the reactor should be dried out.

For drying, the reactor columns can be placed in a chamber through which hot air is blown.

The drying chamber is built of fireproof material and lagged on the inside with a layer of thermal insulation (asbestos, glass-wool matting) 10 to 15 mm thick. The top and bottom of the chamber should have ventilating openings equipped with slide valves for temperature control.

In practice, the reactors to be mounted are frequently dried out by the passage of current, with lengths of steel sections or pieces of steel scrap placed into the hollow of the column for current buildup. The voltage applied to the reactor terminals is anywhere from 36 to 60 V. The reactor may be connected to the supply line provided the insulation resistance, both to earth and between the phase coils, of the reactor heated to 60-70°C is at least 1 MΩ per kilovolt of the operating voltage.

Once the condition of the reactor insulation has been found adequate, the reactor is subjected to a high-voltage test. The commercial-frequency test voltage applied for one minute is 32 kV for 6-kV reactors and 42 kV for 10-kV reactors.

Mounting. The phases of a reactor are moved to the installation site on a truck, or they can be mounted on a

platform made up of boards 50 mm thick and then transported on rollers. The pulling device employed is invariably an electric winch.

With the three phases arranged in a vertical reactor bank within the switchgear cell, the installation procedure is determined by the fact that the reactor bank exceeds, as a rule, the cell doors in height. Therefore, the first to be installed is the top-phase reactor under which the middle-phase and the bottom-phase reactors are placed.

The top-phase reactor is lifted with a hoist secured to an I beam at the top of the cell. Size 12 channel is placed under the top-phase reactor to attach hoisting ropes. Wooden spacers are put between the rope and the reactor concrete column to avoid damage to the latter. Once the top-phase reactor is lifted in place, screwed on its lower bolts are round-base support insulators provided with additional oval base fittings. The base fittings are located so that their holes are exactly in line with the mating bolts of the next, middle-phase reactor also moved into the cell at this stage.

The top phase reactor is then lowered onto the middle-phase one, and the two reactors are fastened together by means of the oval base fittings. At this point the channel securing the hoisting ropes is transferred under the middle-phase reactor, and the two reactors are lifted to the top of the cell. The same procedure is then followed to join the top-phase and the middle-phase reactors to the bottom-phase one so as to form a single unit.

In the course of assembly, cardboard pads 2-3 mm thick are placed on the caps and under the base fittings of the support insulators to cushion the unit against shocks during the passage of short-circuit currents through the reactor. The same pads are recommended for use instead of steel shims in order to correct any misalignments found while aligning the reactor bank. Prior to being fixed finally on its foundation, the reactor bank is plumbed and levelled.

There are different ways of mounting and fixing a fully assembled reactor bank on its foundation. For example, the complete assembly is lowered, with a channel placed under the bottom-phase reactor, on a masonry ring one brick thick laid by builders on the floor of the switchgear structure. The properly laid masonry ring runs through the centres

of the insulators on the bottom-phase reactor, with the fastening bolts, passed through the holes in the base fittings, overhanging on both sides. Then cement mortar is poured around the reactor base within the erected shuttering.

After a reactor has been mounted the flanges of the lower post insulators are connected to a 40 × 4 mm earthing busbar so that it does not form a closed turn and a break is left between the flanges of any two insulators. A closed turn would result in eddy currents and accompanying heating.

If a reactor bank is assembled outside the switchgear cell, the bottom-phase reactor is the one to start with.

15. Mounting of Valve-Type Lightning Arresters

Design. Lighting arresters are safety devices designed to protect electrical equipment from overvoltages due to atmospheric disturbances.

The design and main mounting dimensions of an PBII valve-type lightning arrester ("B" stands for "valve-type", "II", for "substation") are shown in Fig. 83. The arrester operates as follows. Spark gaps *4* break down and disk-shaped current-limiting elements *5* become a low resistance when acted on by a lightning surge, thus providing a discharge path to earth for the affected network.

The mass of an PBII-6 arrester is 9.4 kg, and that of an PBII-10, arrester, 11.5 kg.

Visual inspection. Before erection, lightning arresters must be inspected for broken porcelain and fittings, and also for missing parts. They should be lightly shaken to make sure that no rattling can be heard from within; otherwise, it is a sign that the internal parts are loose. In such a case, the defective arrester should be sent to a laboratory or a workshop for reassembly.

Mounting of lightning arresters. Two basic methods are used for mounting the lightning arresters. The first way is to suspend them by the hanger eye and secure with a clip made from 30 × 3 mm steel strip to prevent the arrester from swinging. More frequently arresters are affixed directly to a metal support by means of a band made from 60 × × 6 mm steel strip.

After mounting, each lightning arrester is connected to the earthing bus by a 40 × 4 mm steel strip. The distance between the earthing bus and the lightning arrester should

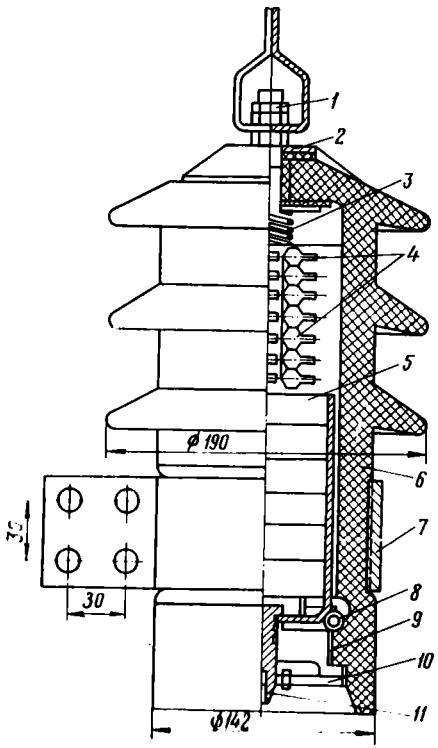


Fig. 83. PBII-10 valve-type lightning arrester

1—terminal; *2*—rubber washer; *3*—spring; *4*—spark gaps; *5*—stack of disk-shaped current-limiting elements; *6*—porcelain casing; *7*—band; *8*—retaining spring; *9*—sealer; *10*—outer diaphragm; *11*—earthing bolt

be as short as practical, so as to keep the resistance of the earth connection to a minimum.

The top contact bolt of the arrester is connected to the respective bus. When connecting a lightning arrester either to a power bus or an earthing bus, great care must be taken that no mechanical stress will be experienced by the rela-

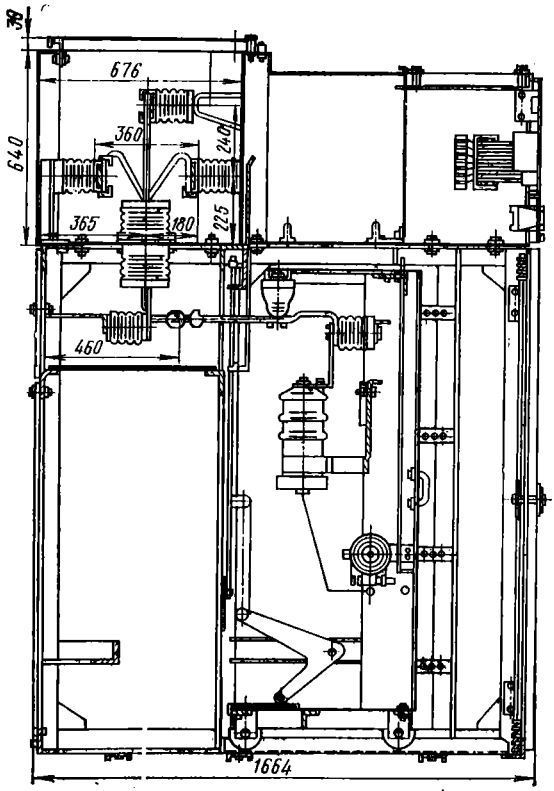


Fig. 84. РВП-10 arrester installed in КРУ unit

tively weak contacts of the arrester, or they may become loose, the arrester may become airleaky and break down.

Figure 84 depicts an РВП-10 arrester mounted on a roll-out truck in a КРУ unit.

16. Installation of Busbars

Indoor substations for 6-10-kV service mainly employ aluminium busbars of rectangular cross section. Their specifications are given in Table 11.

Table 11

Basic Specifications of Rectangular Aluminium Busbars

Dimensions, mm	Mass, kg/m	Dimensions, mm	Mass, kg/m
20×3	0.126	60×6	0.975
25×3	0.202	80×8	1.728
30×5	0.405	80×10	2.160
40×4	0.432	100×10	2.70
50×5	0.675		

The main operations carried out to install busbars in an indoor substation are the straightening, cutting, bending, and joining of busbars and their connection to switchgear contacts.

Straightening. Busbars should be straightened if their curvature is greater than 2 mm per running metre. In the

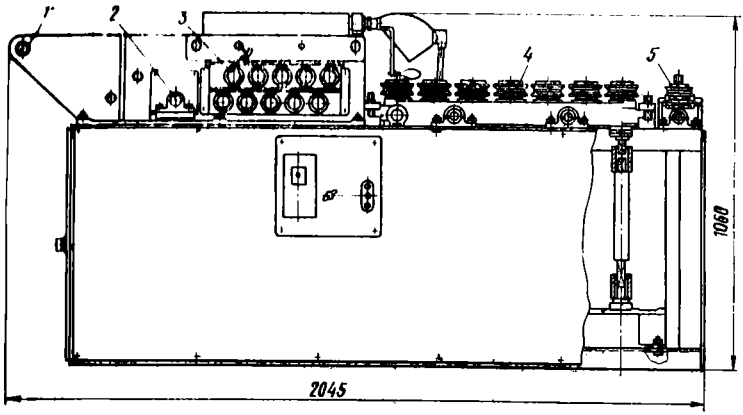


Fig. 85. ВПШ-140М roll-type bus straightener

case of large-scale work, ВПШ-140М roll straightener (Fig. 85) is employed. Busbars are flattened by horizontal rolls *3* and straightened edgewise by vertical rolls *4*. The roll straightener also has guide rolls *2* and deflector rolls *5* the function of which is to prevent the busbar from being deform-

ed as it leaves the machine. The busbar to be straightened delivered as a coil is mounted on shaft *1*. The straightener capacity ranges from 30 × 3 mm to 140 × 12 mm busbars.

On small sites busbars are manually straightened on a straightening plate or T-beam with a mallet or hammer;

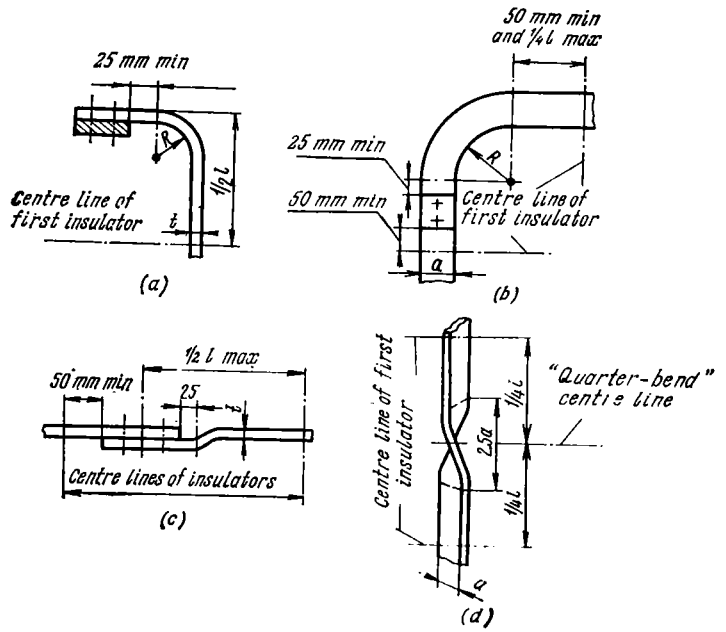


Fig. 86. Bending of busbars

(*a*) bend on flat; (*b*) bend on edge; (*c*) offset bend; (*d*) quarter-turn bend (*l*—distance between supports of busbar)

in the latter case blows are delivered through an aluminium cushioning pad.

Cutting. Busbars are cut with circular saws, electrically powered hack-saws, lever shears, or on shearing presses.

Bending. Busbars are bent to templates made beforeh and of steel wire 3 to 5 mm in diameter. In the course of installation work, lengths of light-section aluminium busbars serve the same purpose.

Busbars are most commonly bent on flat and on edge (Figs 86*a* and *b*). Minimum bending radius may be taken

from Table 12. Busbars may also be offset and quarter-turn bent (Figs 86*c* and *d*).

Table 12

On-Flat and On-Edge Bending of Busbars

Type of bend	Busbar size, mm	Minimum radius of bend from inner edge, mm
Bend on flat	Up to 50×5	2*t*
	100×10	2.5*t*
Bend on edge	Up to 50×5	1.5*a*
	100×10	2*a*

Note: *a* – busbar width, *t* – busbar thickness.

Mechanisms and fixtures used in bending busbars are shown in Figs 87 and 88.

Joining of busbars with bolts. Lap joints are most commonly used. Typical examples of bolt-hole layouts are given in Fig. 89. The sizes of bolts and holes may be taken from Table 13.

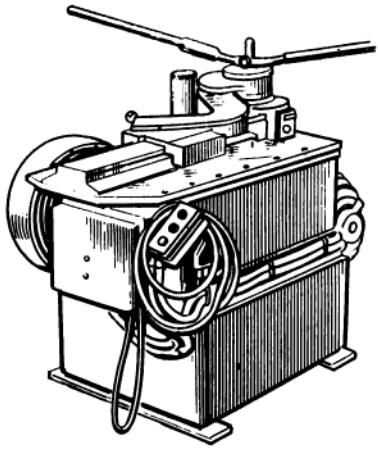
Table 13

Diameters of Bolts and Bolt-Holes in Busbars

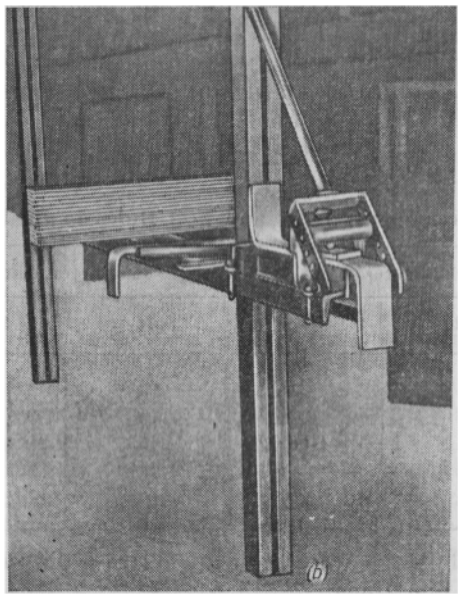
Diameter, mm		Diameter, mm	
bolt	hole	bolt	hole
6	7	12	15
8	9	14	16
9	10.5	15	17
10	11.5	16	18
12	13.5	18	20

Holes in busbars are punched on IIH-1 presses or drilled on drilling machines.

The contact surfaces of the busbars must be thoroughly prepared for joining. It is good practice to use specialized machines for the purpose. Contact surfaces of aluminium



(a)



(b)

Fig. 87. Busbar benders

a) bus-and-pipe bender; (b) hand-operated roller-type on-flat busbar bender

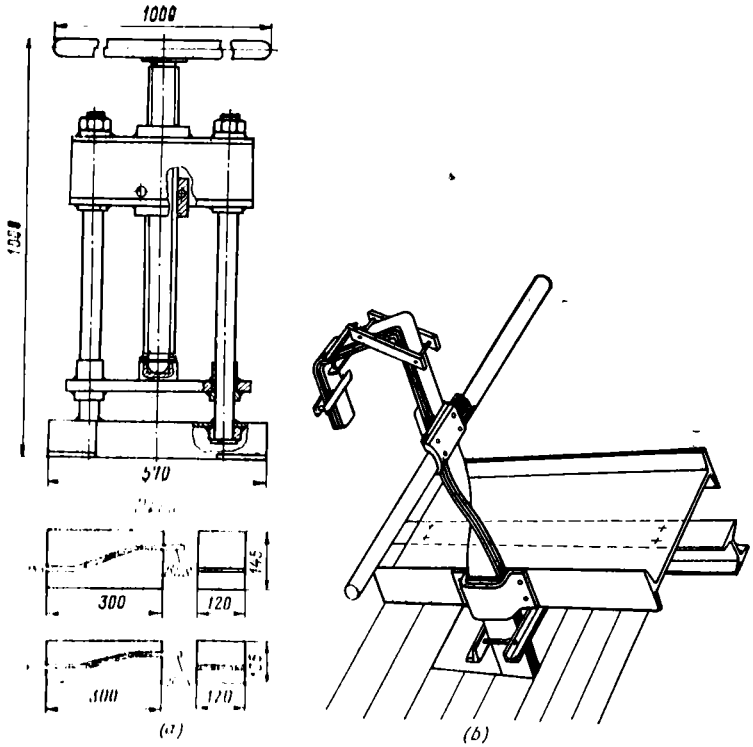


Fig. 88. Busbar benders

(*a*) offset bending screw press and dies; (*b*) quarter-turn bending fixture

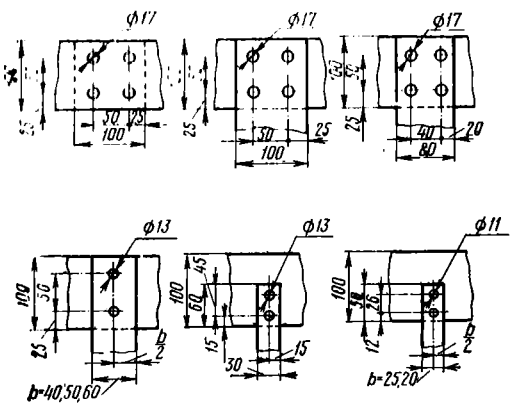


Fig. 89. Bolt-hole layouts

busbars are worked under a coating of petroleum jelly. In the case of small-scale work, the contact surfaces of the busbars may be cleaned with bastard files, card files, etc. One must remember that the contact surfaces of the busbars must never be polished nor grinded lest the contact be impaired.

Joining of busbars by electric welding. In modern practice the switchgear installations being erected are for the most part equipped with aluminium busbars. With the exception of detachable joints, busbars are joined by electrical

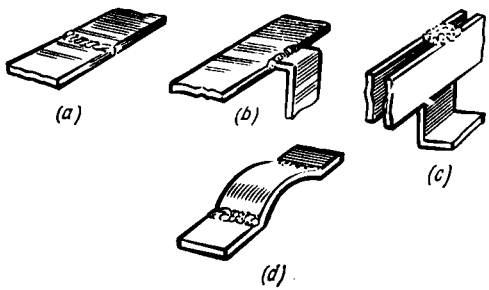


Fig. 90. Welded bus joints

(*a*) butt-welded joint; (*b*) tee of bus installed on flat; (*c*) tee of main buses installed on edge; (*d*) welded bus expansion compensator

welding. The work is done by qualified welders. Use is made of welding transformers having a secondary (welding) voltage of 65 V. The materials employed are carbon or graphitized electrodes, filler rods, and welding fluxes. Filler rods are usually made on the spot of busbar sections.

Aluminium busbars are welded with the use of a ВАМИ flux which is diluted with water until it becomes pasty. It takes about 30 to 35 g of water for 100 g of flux. The busbar edges to be welded together and the filler rods are given a coat of the flux prepared 25 to 30 minutes before the welding. The areas to be fluxed should be pre-cleaned with a wire brush.

The most typical examples of welded bus joints are given in Fig. 90.

Installation of buses. From the general view of a main busbar section in the substation shown in Fig. 91 it can be seen that the buses may be installed on flat and on edge and

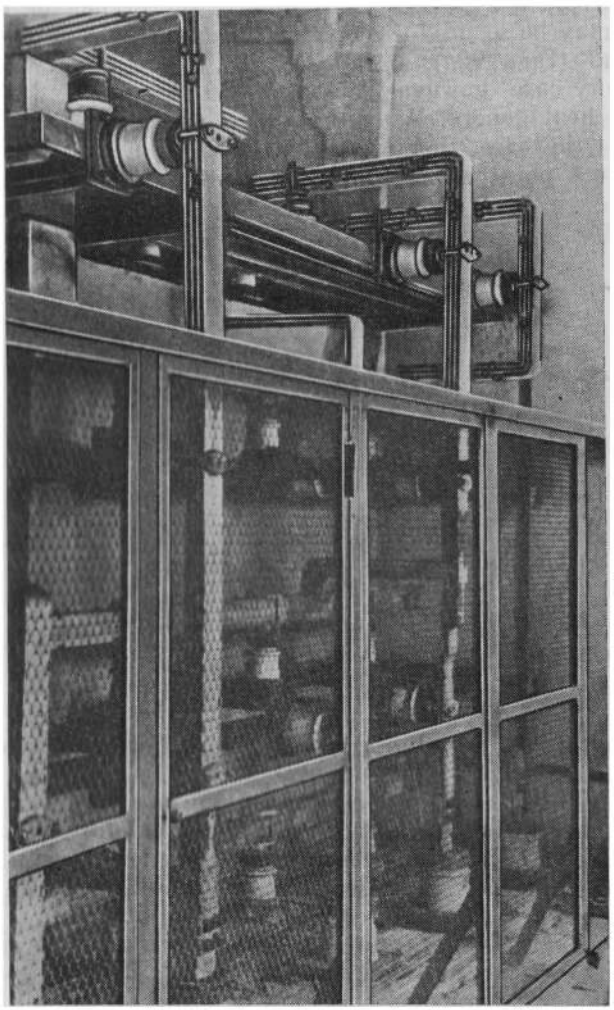


Fig. 91. Busbar section in 6-kV indoor substation

held in place by clamps. In some cases branch or tee-off buses may be secured directly to the caps of the support insulators (Fig. 92*a*).

In any case, however, buses must be free to expand due to the heat generated by their load and short-circuit currents. Otherwise, the internal stresses set up in them may grow to a point where they will cause warpage of the bus-

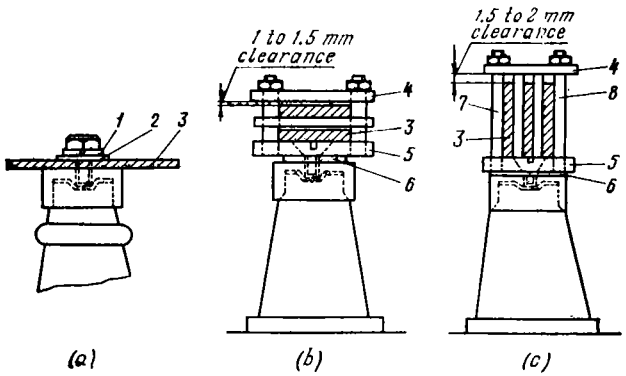


Fig. 92. Securing of busbars on support insulators

a) directly on insulator cap; (*b*) on-flat in busbar clamp; (*c*) on-edge in busbar lamp; *1*—spring washer; *2*—steel washer; *3*—busbar; *4*—upper plate; *5*—lower plate; *6*—cardboard pad; *7*—steel stud; *8*—brass stud

bars, or, if a heavy short-circuit current flows, even destroy the entire busbar structure.

Because of this, busbar clamps have a clearance of 1.5 to 2 mm (Fig. 92*b*, *c*) so that the busbars cannot be clamped dead-fast. For the same reason single-bar buses installed on the insulator caps have oval mounting holes and the bolts have spring washers placed under their heads (Fig. 92*a*).

Bus structures more than 15 metres long must be provided with expansion compensators (Fig. 93).

In indoor substations buses are installed in the following sequence:

First busbar clamps are attached to the caps of the support insulators and the busbars are placed on them. Then the busbars are trued with respect to the longitudinal axis with a wire and levelled with a batten and spirit level. After

this, the tee-off busbars, shaped to templates, are trimmed and placed. Finally, the busbars are joined up and expansion compensators are installed.

A clearance between multibar buses is allowed by inserting distance bars.

Mounting of busbar clamps. One of the studs locking a clamp is made of a nonmagnetic material (brass) to reduce

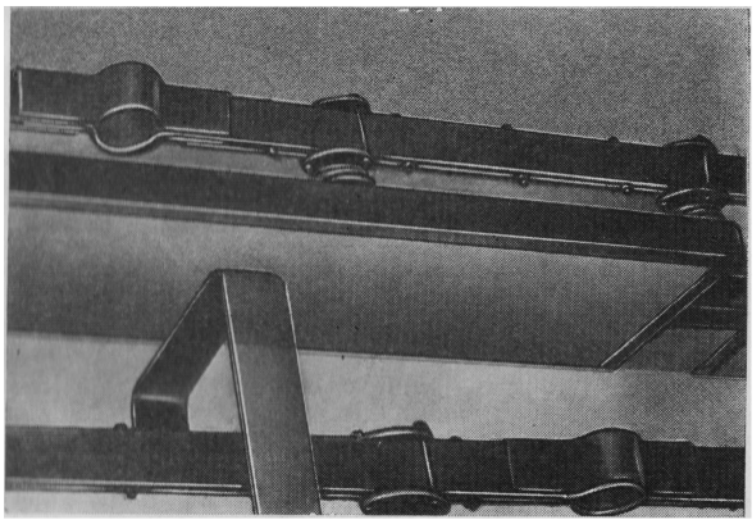


Fig. 93. Bus expansion compensators joined by welding

heating and the accompanying loss of power, as the magnetic circuit is disrupted and no eddy currents can be induced in the clamp parts.

Buses installed in a common horizontal plane are frequently mounted in their clamps. In such cases, the clamps should be turned so that the dynamic forces developed by the flow of short-circuit currents will tend to tighten rather than loosen their bolts.

Connection of busbars to switchgear contacts. This operation poses difficulties in that it may be performed in many ways and that aluminium busbars have to be joined to copper switchgear parts.

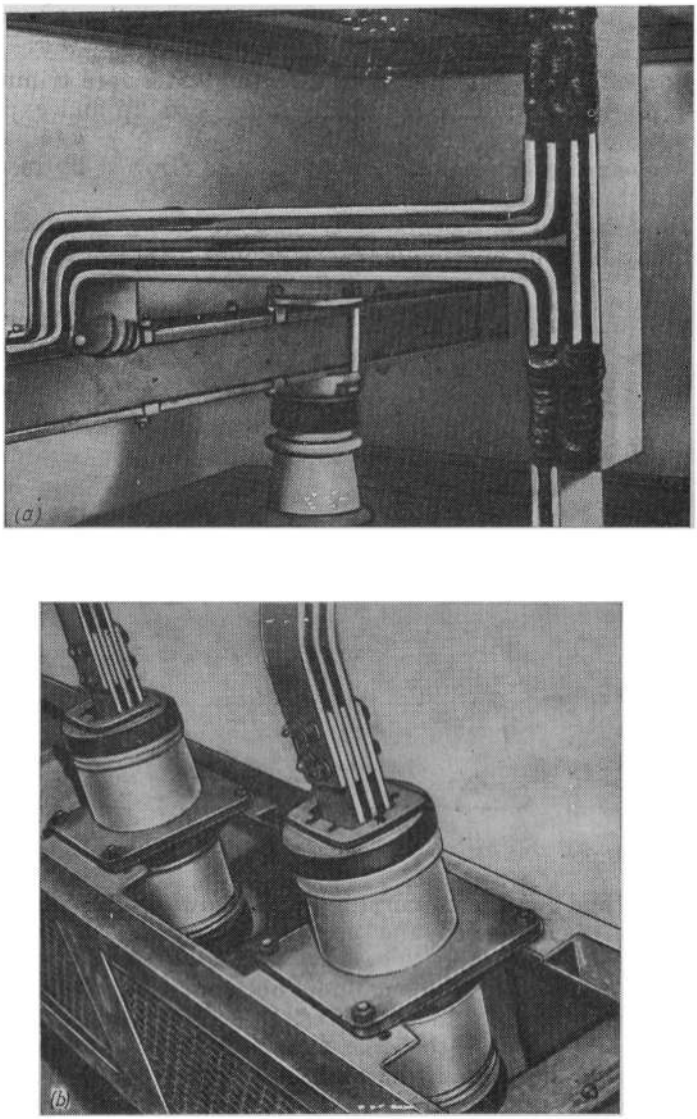


Fig. 94. Installation of busbars

(*a*) intricate bus assembly with welded joints; (*b*) multibar buses passed through bushings

As operating experience has shown, fair results may be obtained by using composite butt-welded copper-aluminium straps. The aluminium end of the strap is welded to a busbar and the copper end is connected to the apparatus.

It is obvious that the smaller the number of joints, the higher the quality of the installation and switchgear reliability. For this reason several Soviet electrical construction organisations prefer to remove the bars out of bushings and pass the tee-off bars directly through them.

Figure 94 shows typical sections and assemblies of bus structures in indoor substations.

Painting of buses. Painting is the last operation in busbar installation. Busbars are painted in different colours for phase identification (colour coding), anticorrosion protection, and better heat radiation.

Busbars are given two coats of ПФ-115 enamel (yellow, green, or red). The second coat is applied with a 50% addition of No. 170 varnish. The duration of air drying is 24 h for the first coat and 48 h for the second. Single-bar buses are painted on all sides. Multibar buses are painted only on the outside and edges.

Bolted joints and places on the buses where temporary safety earthing sets are attached are left unpainted. The latter are contoured with a black paint. Bus clamps are painted together with their buses.

The standard colour code for buses is as follows:

Yellow for 1st phase (*A*)
Green for 2nd phase (*B*)
Red for 3rd phase (*C*)
Black with white stripes for unearthed neutral
Black with violet stripes for earthed neutral
Red for positive d-c pole
Blue for negative d-c pole

Alternative arrangements of main buses in an indoor substation are shown in Fig. 95. The 3rd phase (*C*) and positive buses are always located below the others and nearer the control aisle.

Provision of temperature indicators on bus joints. In indoor substations a check on the temperature of bolted bus joints is provided by pasted-on temperature-sensitive films. These films change colour as the joint temperature

rises. As an alternative, circular pieces of film can be pasted on the bolt heads.

The surfaces to be covered with a temperature-sensitive film should be thoroughly cleaned and wiped with a cloth

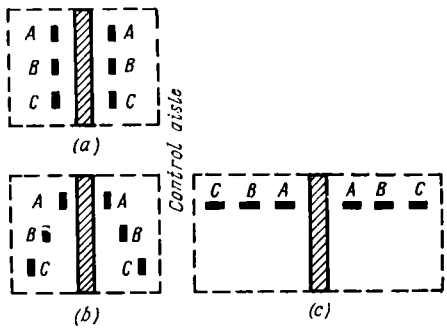


Fig. 95. Arrangement of collecting (main) buses in indoor substation
a) vertical arrangement; (*b*) diagonal arrangement; (c) horizontal arrangemen

moistened with petrol, and then given a coat of benzyl-cellulose varnish, the film is then applied and finished with the same varnish.

17. Installation of KPУ Factory-Assembled Switchgear

Prior to installation each KPУ unit should be thoroughly inspected for any damage to the metal enclosures, doors, paintwork, etc., and for missing parts against the accompanying packing lists. Next the parts (instruments, relays, and buses) shipped separately packed should be examined to make sure that they have not been damaged in transit.

For installation, each KPУ unit is lifted by a crane and moved through a special opening in the switchgear-room wall or through a window opening.

KPУ units should be transported only in a vertical position. Within the switchgear room, it is good practice to move them on suitable trucks. If no trucks are available, use is made of rollers placed under the base of the unit.

All plastering, concreting, and whitewashing in the switch gear room must be completed before the KPУ units are

moved in. On the other hand, the finish floor covering may be laid after switchgear installation.

The metal supports embedded in the floor or ceiling by the builders should be checked for compliance with the drawings.

The embedded supports made from Size 12 channels must above all be precisely horizontal and parallel to one another. The deviation should not exceed 10 mm over the entire length of the support.

The supporting structure is checked by means of a batten placed on both channels and a spirit level put on top of it. The load-bearing surfaces of the channels should be about 5 mm above concrete slab level and 5 mm below finished floor level.

All deviations in the position of the embedded channels must be remedied by the builders, who may weld steel pads to the load-bearing surfaces to make them level.

The embedded channels must be butt-welded and connected to the earthing bus at no less than two points by means of 40 × 4 mm steel strip.

Now the KPV units may be set up on their sites. The switch trucks may be rolled out to reduce the total weight to be handled.

First the outer unit on either of the ends should be installed, taking care to check it with a plumb-bob for verticality and with a level for horizontality. The unit must stand firmly on its base. If it is shaky, steel pads not thicker than 5 mm may be used to level it off.

The switch truck of the unit should roll in smoothly and stand firmly; the fixed and movable isolating contacts should be precisely in line.

The second unit is then joined to the first one, the third to the second, etc., until all the units in a given switchgear are set up. The units are joined together by M12 bolts. The relative position of the units is checked by means of the red painted locating holes in the sides. The locating holes of two adjoining units must coincide.

The units are joined up, beginning with an end unit and the one next to it, tightening first the lower and then the upper bolts. When it is necessary to shift a unit slightly in the course of installation, force should only be applied to

the underframes because the side walls may otherwise be easily damaged beyond repair.

The entire switchgear is then brought into alignment along the front. The units are considered properly aligned if the upper edges of all the doors fall in one line and their fronts are in the same plane, a condition which can be easily checked by a wire strung from end to end.

The underframes of the units are welded to the support channels at four points and the channels are connected to the earthing bus with 40 × 4 mm steel strip at not less than two points.

Next the primary circuit buses are installed. First, the temporary fastenings provided for transportation are removed from the tee-off buses; the main buses are put in place according to their colour coding (yellow, green, red) and so that the numerals on their ends are the same as those of the switchgear units between which they are to be installed.

Bus sections and tee-offs are bolted together in the regular manner.

The secondary-circuit buses are unpacked, laid in the ducts provided for them, and connected to the terminals according to their numerals. The connections should be checked against the diagram attached to each switchgear unit.

Then the indicating-metering instruments and protective devices are mounted if they have been removed for safety in transit.

The equipment in KPУ units is earthed througn the supporting metal framework. Because of this, the metal under the bolts must be cleaned bright and the bolts fully tightened. The bus ducts should also be checked to see that they have been snugly fastened together and to the framework of the units.

Before KPУ switchgear may be put into service all the equipment installed in units (circuit breakers, operating mechanisms, instrument transformers, etc.) must be checked and tested.

Problems

1. Write up a sequence card for mounting three ОФ-10-375 support insulators on metalwork.
2. Write up a sequence of operations for mounting three П-10/1000 bushings on a frame built into a switchgear structure floor.

3. Make out a bill of equipment and materials and a list of tools, mechanisms, and fixtures required for mounting an РВ-10/600 three-pole isolator complete with its operating mechanism.

4. Write up a sequence card for mounting a ВМП-10 oil circuit breaker complete with a ПЭ-11 operating mechanism on the metalwork of a cubicle-type switchgear structure.

5. Write up a sequence of operations for mounting an МГ-10 oil circuit breaker complete with its operating mechanism.

6. Write up a sequence card for mounting two ТПШЛ-10/1000 current transformers and a П-10/1000 bushing in an indoor substation floor.

7. Describe the types and sequence of the pre-installation tests on НОМ and НТМК voltage transformers.

8. Write up a sequence of operations for mounting the three phases of a vertical cast-in-concrete reactor bank in an indoor switchgear cell.

9. Write up the mounting of КРУ units on a channel frame in an indoor substation room.

CHAPTER 3

Installation of Outdoor Primary Circuit Switchgear

18. Mounting of Support and Bushing Insulators

Support insulators. Some of the support insulators used in outdoor switchgear are characterized in Table 14 and Fig. 96.

Table 14

Basic Specifications of Outdoor Support Insulators

Type designation	Dimensions, mm			Mass, kg
	height	diameter	fixing dimension	
ШН-6	170	140	11	2.54
ШН-10	190	160	11	4.1
ИШД-10	210	250	15	12.7
ИШД-35	400	430	18	44.6
ШТ-35	400	370	15	32.5
СТ-35	420	170	12	15.45

Note. The following designations are used: Ш and ШТ – pin-type; И – insulator; Н – outdoor; Д – modified; КО – stack, support; СТ – shackle

For 110-kV service, 35-kV insulators are assembled in a stack of three. For example, an insulator stack made up of three ИШД-35 insulators and rated for 110 kV is designated ЗИШД-35.

Some of the stock-produced 110-kV support insulator stacks are the КО-110У and the СТ-110.

The mounting of support insulators on a bridge-type busbar structure (Fig. 97) provides an example of their installation for outdoor service. The insulators are bolted up in place. The bottom of the insulator base fitting and the

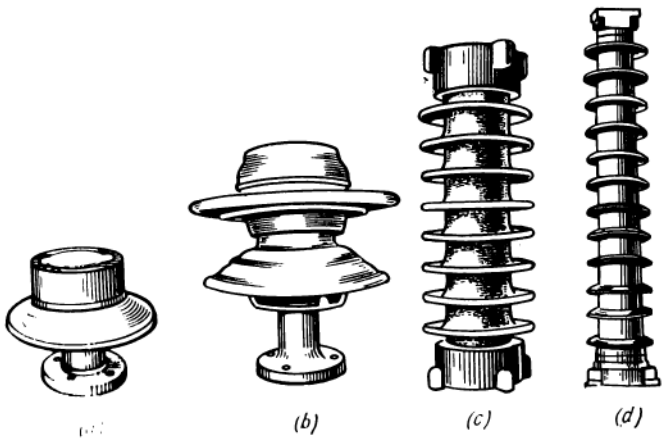


Fig. 96. Outdoor support insulators
(*a*) ИШ-10; (*b*) ШТ-35; (*c*) СО-35; (*d*) СТ-110

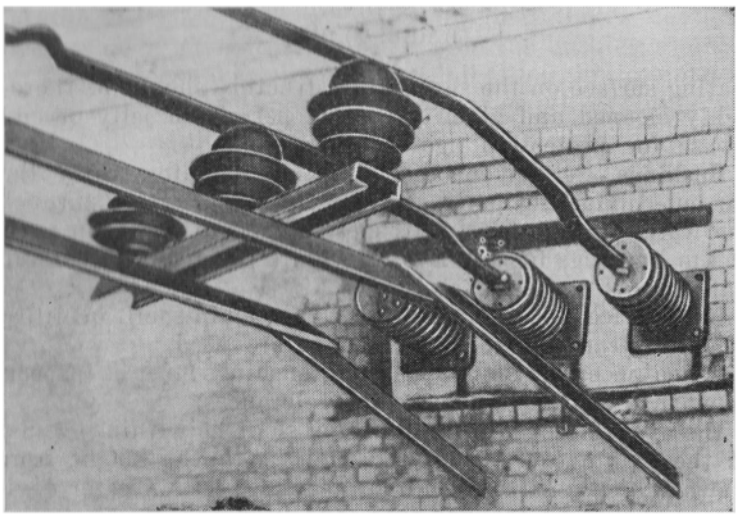


Fig. 97. ИШД-35 insulators mounted on bridge-type busbar structure

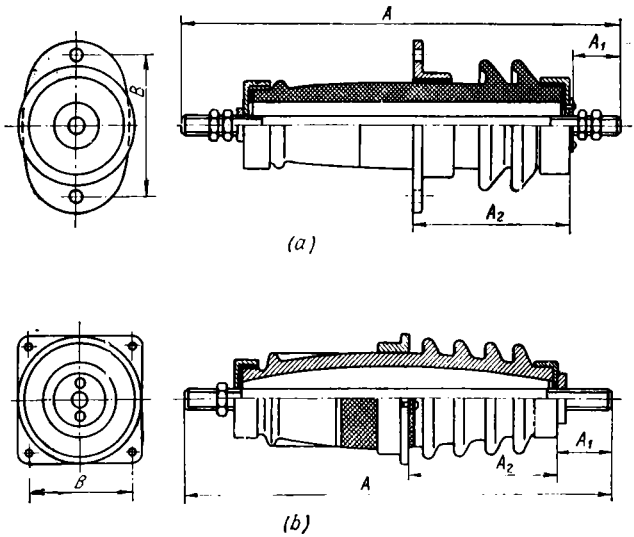


Fig. 98. Outdoor service-entrance bushings
(*a*) ПНБ; (*b*) ПНВ

seating surface on the supporting structure should be thoroughly cleaned and given a coat of petroleum jelly or cup grease for protection against corrosion.

Bushings. Service-entrance bushing insulators carry the current-conducting parts of an outdoor substation through the walls of an indoor switchgear structure. Data on some of the bushings for 110-kV service are given in Fig. 98 and Table 15.

For service at 110 kV and over, porcelain-shell, oil-filled service-entrance bushing insulators are used.

When accepted for installation, bushings must be inspected with regard to the following tolerances:

the overall length of the bushing shall be within ± 5 mm of the manufacturer's specification, with the height from flange to head within ± 3 mm. Bushings with greater deviations should be grouped into, and used as, sets of similar deviation;

the offset of the current-carrying rod relative to the bushing axis shall not exceed ± 1 mm. Otherwise, the position

Table 15

Basic Specifications of Outdoor Bushings

Type designation	Dimensions (Fig. 98), mm					Mass, kg
	A	A_1	A_2	*B*	mounting hole, dia	
ПНБ-6/400	530	47	191	175	40	9.3
ПНБ-6/600	550	57	191	175	40	9.9
ПНБ-6/1000	580	70	215	175	40	13.0
ПНБ 10/400	605	47	240	175	14	10.0
ПНБ 10/600	625	57	240	175	14	10.82
ПНБ 10/1000	710	70	300	240	17	20.6
ПНБ 10/1500	710	70	300	240	17	24.0

Note. The following designations are used: П — bushing; Н — outdoor; Б and Б — class according to load at collapse; 6, 10 — voltage rating, kV; 400, 600, 1000, 1500 — current rating, A.

of the rod should be corrected by installing a centering washer or by repositioning the cap on the bushing.

When accepted for installation, oil-filled service-entrance bushings must be checked for leakage of oil. For this pur-

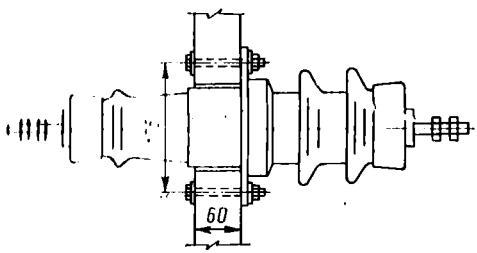


Fig. 99. Bushing mounted for outdoor service

pose, the bushing is set upright on a trestle of steel angles in a room maintained at a temperature of 15 to 20°C. After 48 hours the bushing is inspected for any traces of oil leakage. If leakage is detected, the sealed bolted joints should be tightened, taking care to tighten the bolts by turns,

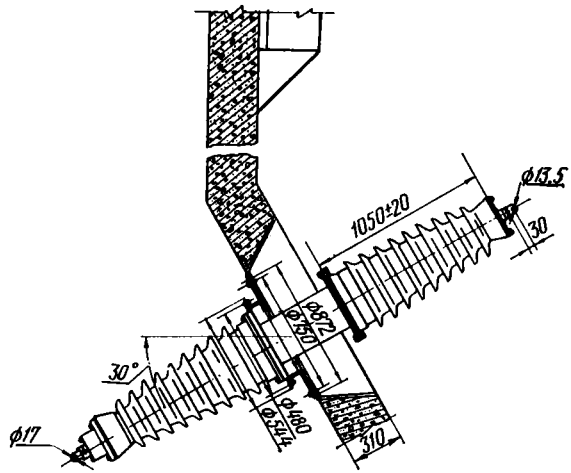


Fig. 100. MH-110 oil-filled service-entrance bushing mounted in place

through no more than one-sixth revolution at a time. Besides, oil-filled service-entrance bushings are tested for air-tightness under a pressure of 1.5 atm.

Bushings rated for 35 kV and below are mounted in the regular way as discussed above.

A bushing mounted for outdoor service is shown in Fig. 99.

MH-110 oil-filled service-entrance bushings are mounted on a steel plate embedded in the wall opening of the switchgear structure. To avoid condensation around the bushing and on its surface, the mounting plate should be lagged on the inside (within the switchgear room) with a layer of asbestos or glass cloth. An MH-110 oil-filled service-entrance bushing mounted in place is depicted in Fig. 100.

19. Mounting of Isolators

Design. Of the isolators designed for outdoor use, РЛНД line-circuit two-column outdoor isolators are frequently used. Considered below by way of example is the РЛНД2-35 /600-1000 modification of this unit (the number 2 stands for

two sets of earthing blades). The mass of the isolator is 435 kg.

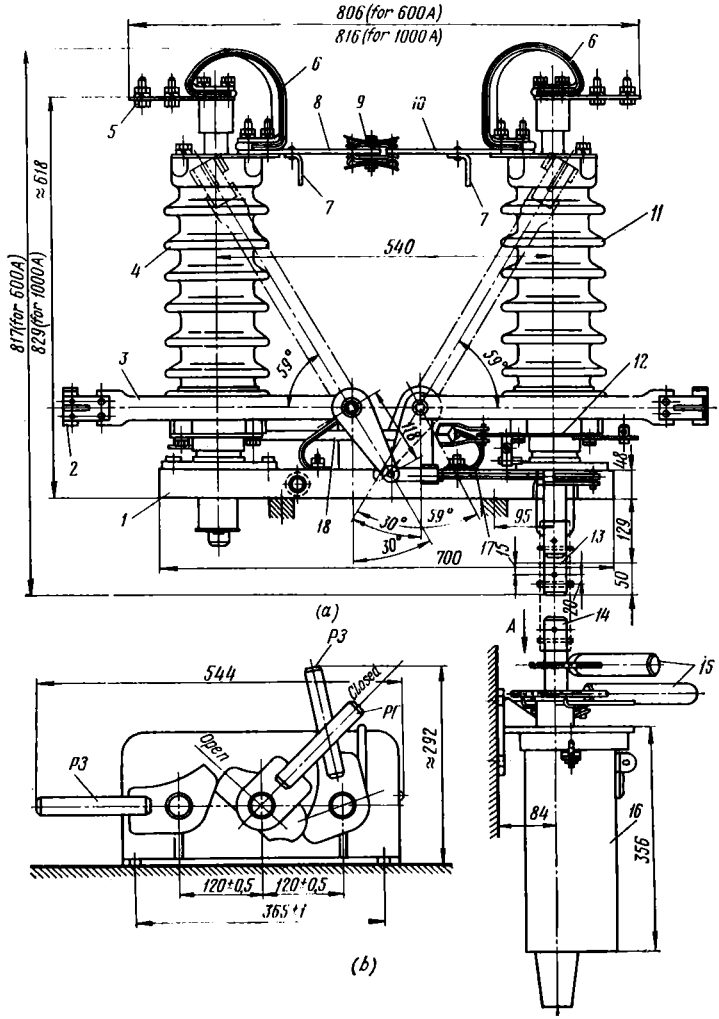
The base of each single-pole unit of the isolator (Figs. 101*a* and *b*) is channel *1* having cast-iron bearings welded on both sides. Welded on top of the bearings are levers *12* coupled by interphase link rod *18*. The levers mount stick insulators *4* and *11* with contact blades *8* and *10* secured at the top. Female blade *8* has finger contacts *9* fitted on it. The contact blades are connected to line terminals *5* by banks *6* of copper strips.

Shaft *13* brought under the base channel communicates rotation to the entire system when operating mechanism *16* is actuated by control levers *15*. If the operating mechanism is made to turn shaft *13* along with the bearing and insulator *11* secured on its lever, the insulator with male blade *10* will be rotated either clockwise or counterclockwise, depending on which way the control lever of the operating mechanism is turned. Coupled to insulator *11* with link rod *18*, insulator *4* will also be rotated, together with female blade *8*, yet in the opposite direction to insulator *11*. As a result, the contact blades will close up or part, thus making or breaking the line connected to the isolator.

The isolator is provided with earthing blades *3* in order to complete earth connection for both sides of the subcircuit involved after it has been broken. The earthing blade is a length of steel pipe having one of its ends welded to rotary shaft *23* (Fig. 101*c*) and the other fitted with brass contact *2* (see Fig. 101*a*).

Once the contact blades have parted, the earthing blades rise and close on fixed contacts *7* of the contact blades. The latter and the subcircuits involved are thereby returned to earth by earthing blade *3* which is connected to the base channel of the isolator and hence to the grounding mat by flexible strap *17*. The earthing blades are controlled by the same operating mechanism as the contact blades of the main contact system. They are coupled to the operating mechanism via intermediate arm *22* (see Fig. 101*c*).

The single-pole unit that is coupled to the operating mechanism is referred to as driving, and the other two units, as driven. Both the middle phase assembly or either of the outer ones may be the driving unit, depending on where the



operating mechanism is installed. As far as the main contact system is concerned, movement is transmitted to the driven units through the interphase link rods shown in Fig. 101*c*.

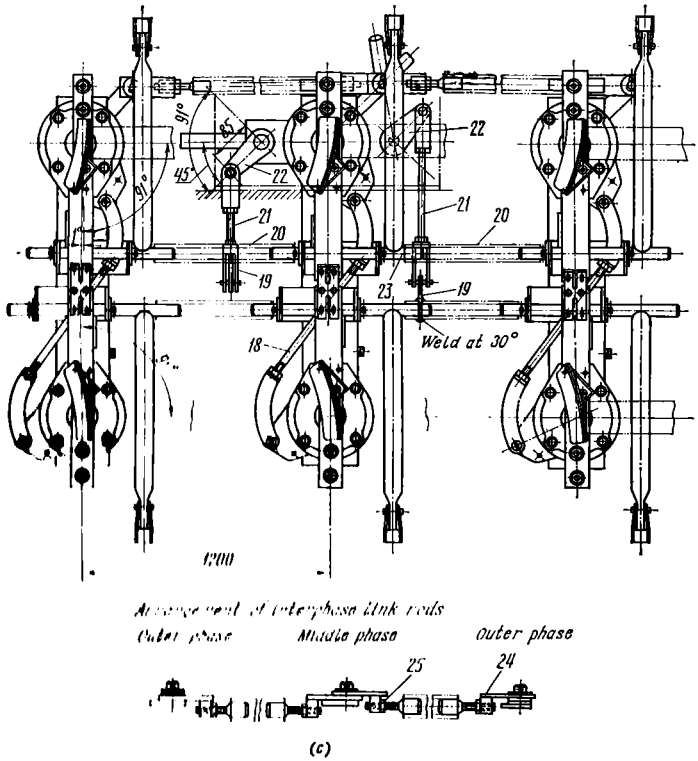


Fig. 101. РЗПП/Ц 35/600 1000 isolator for outdoor service
(a) installation drawing, (b) operating mechanism, top view (ПГ—contact-blade control lever, НЗ—earthing blade control lever); (c) top view

The isolator is operated by a ПРН-220 lever-type mechanism (see Fig. 101*b*) intended for outdoor use.

Storage, unpacking, and inspection. The insulator delivered to the site should be kept under a shed to shut out atmospheric precipitation in order to avoid corrosion damage to specific parts. Care should be exercised in unpacking the isolator so as not to damage the porcelain and other parts.

Once unpacked, the isolator should be thoroughly inspected for damage that may have been done to it during

transportation, storage, or unpacking. Special attention should be paid to the condition of the porcelain, contacts, and flexible straps.

Mounting of the isolator and operating mechanism. Layouts for mounting the isolator and its operating mechanism are shown in Fig. 102. Prior to mounting the isolator, its base

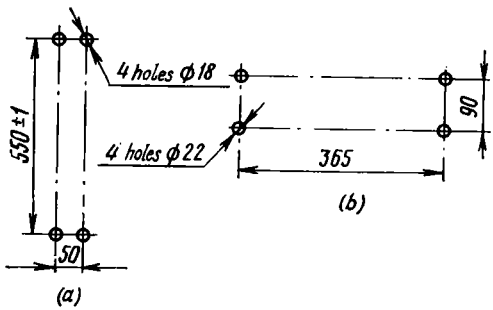


Fig. 102. Bolt-hole layouts for mounting
(*a*) isolator; (*b*) operating mechanism

plane is aligned with a batten and level. Small horizontal misalignment may be remedied by placing steel shims under the bases of the single-pole units.

The isolator is lifted onto its support structure by a truck crane. When the three single-pole units are in place, each of them is slowly closed by hand as far as it will go to check on blade travel. The axes of the contact blades must be 5 mm beyond the midposition as measured from the centre line of the single-pole unit. The end clearance between the contact blades must not exceed 2-3 mm. Variations, if any, from the specified values are eliminated by adjusting the length of link rod *18* (see Fig. 101*a*).

Before separate single-pole units may be assembled into a three-pole unit, each unit must be checked for contact pressure. To do this, inserted between the finger contacts of the open isolator is a length of degreased copper bus equal in cross-section area to the male blade entering the finger contacts. The bus is provided with a hole to couple a load gauge by means of which the pulling force is determined, thus enabling one to estimate the contact pressure.

According to the manufacturer's specifications for the РЛНД 2-35/600 isolator, the pulling force applied to the bus and directed along the female blade should be at least 16 to 18 kg. For an isolator of the same type rated for 1 000 A, the pulling force must be anywhere between 18 and 20 kg. If the contact pressure has to be somewhat increased, the bolts of the finger contacts are tightened.

At the same time as the isolator is secured in place, the interphase link rods are installed. End fittings *24* and inserts *25* (see Fig. 101*c*) are furnished by the manufacturer as parts of the links rods. The inserts are complemented by lengths of 1-inch steel pipe selected to suit job requirements. The inserts are fitted inside the pipes and welded to the latter. To connect the single-pole units into a three-pole unit, the tie rods secured to end fitting *24* are attached to the levers of the isolator.

To connect (on one side) the earthing blades of the single-pole units, lengths *20* (see Fig. 101*c*) of 1-inch steel pipe are fitted on the ends of their shafts *23*. Actuating lever *19* supplied by the manufacturer is slipped preliminarily over one of the pipes. The pipes are secured to the shafts with tapered pins 8 × 45 mm or by welding. The earthing blades should be in the closed position while the pipes are installed.

Actuating lever *19* should be so mounted that its centre line is 185 to 190 mm away from the longitudinal axis of the pole assembly and makes an angle of 29-30° to the vertical. The actuating lever is then coupled to intermediate arm *22* by means of link rod *21* supplied by the manufacturer. The length of the link rod should be so adjusted that the centre line of the intermediate arm makes an angle 45° to the horizontal. The same procedure is followed to install the linkage of the earthing blades on the other side of the unit.

Levers *12* (see Fig. 101*a*) communicating motion to the contact blades are linked to the operating mechanism by means of a 1 1/4-inch steel pipe. This pipe couples shaft *13* of the driving pole of the isolator to shaft *14* of the operating mechanism. First the pipe is fitted on the shaft of the pre-closed isolator, and then the operating mechanism, also in the closed position, is installed to match the pipe. In either case the pipe is secured in place with pins or by welding.

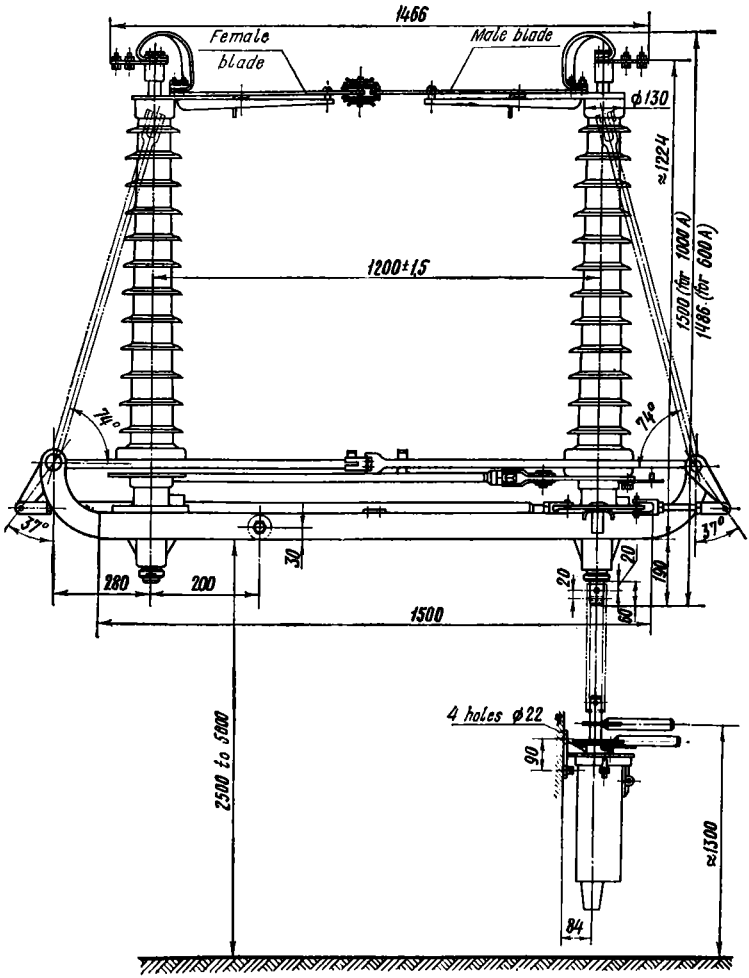


Fig. 103. РЛНД2-110 isolator

With the operating mechanism coupled to the isolator, the angle of blade rotation is checked by setting the control lever of the operating mechanism to the OPENposition. The contact blades of the three poles must turn through 90 to

92 deg. The angle of rotation can be adjusted by shifting the latch of the operating mechanism that locks in the open position.

To adjust the travel of the contact blades, use is made of the end fittings of the interphase and in-phase link rods. Besides, the rotatable columns are provided with adjustable stops. When closed, the properly adjusted blades must go 1 deg. beyond the longitudinal axis of the pole assembly.

The same procedure is followed to couple the shafts of intermediate arms *22* (see Fig. 101*c*) of the isolator to the auxiliary shafts of the operating mechanism rotating the earthing blades. For the time of installation both the earthing blades and the control levers of the operating mechanism are set to the closed position. In adjusting the travel of the earthing blades, account should be taken of the fact that the blades of the poles most removed from the operating mechanism must be the first to touch the fixed contacts.

On completion of adjustment all the articulated joints of the isolator and its operating mechanism should be given a coat of grease recommended by the manufacturer, e.g. ЦИАТИМ 201 mixed with 10 per cent (by weight) of graphite. The contact surfaces are coated with the same grease without any admixture.

The difference between the РЛНД-2 and the РЛНД-1 isolator is that the latter has earthing blades only on one side.

The design of an isolator of the same type rated for 110 kV and hence designated РЛНД/Д2 110 is illustrated in Fig. 103. In mounting the isolator, one should be guided by the foregoing.

70. Mounting of Short-Circuiting, Isolating and Earthing Switches

In some substations operated at 35 and 110 kV, expensive circuit breakers are substituted by jointly used short-circuiting and isolating switches. These units are series-connected into the circuit diagrammed in Fig. 104.

Should a fault occur within transformer *8*, a pulse from its protective gear will be applied to closing coil *9* or *10* of the short circuiter operating mechanism. Latch *11* hold-

ing short-circuiting switch *1* in the open position will be thus released, the switch will be closed by spring *12*, and an intentional shorting to earth will take place.

In consequence, the winding of relay *3* built into the operating mechanism of isolating switch *6* will be energized

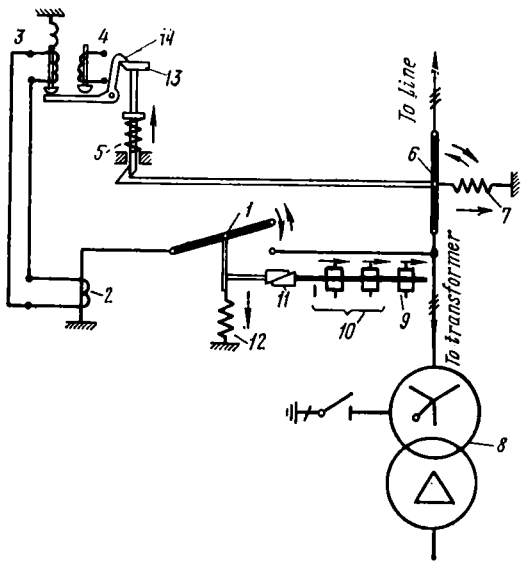


Fig. 104. Operation of short-circuiting and isolating switches

by current transformer *2* connected to the earthing busbar of the short-circuiting switch. The armature of the relay will rise and wind up its spring. The intentional shorting will trip the circuit breaker at the supply end of the line. Relay *3* will be de-energized, and its armature will be forced by gravity and by the wound up spring to strike against the tail of catch *14*, thus releasing latch *13* of the operating mechanism of isolating switch *6*; the latter will be opened by spring *7*. So in the event of a fault the substation will be isolated from the supply line.

Relay *3* termed "latching" enables the required sequence to be followed in the operation of the short-circuiting

switch, the circuit breaker at the supply end of the line, and the isolating switch.

The isolating switch can be promptly opened, irrespective of the short-circuiting switch position, using trip coil *4* provided for the purpose in its operating mechanism. Trip coil *4* is operated from an individual power supply. The switch is likewise opened by releasing latch *13* with spring *5*.

Once the isolating switch has interrupted the circuit, a specially installed device known as the automatic recloser (АПВ) functions to resume power supply to the other loads connected to the same line.

КЗ-110 short-circuiting switch (Fig. 105). The switch comprises welded base *4* mounted on porcelain insulators *3* and used to accommodate a spring-actuated mechanism, stack *5* of three ИОСК-35 support insulators, fixed contacts *7*, and moving blade *9*. Busbar *8* serves to complete the earth connection for the blade, and terminal *6* to connect the line. Insert *10* of rigid PVC is built into tie rod *11* coupling the switch to its operating mechanism *1*. Transformer *2* of the ТОЛЮ-5 type is employed to energize a latching relay in the operating mechanism. The mass of the short-circuiting switch is 180 kg.

The switch is operated by a ПГ-10-К mechanism. Once the protective gear has brought the operating mechanism into action, the short-circuiting switch is closed automatically by its spring-actuated mechanism. Provision is also made for manual closure. The switch can be opened, and the spring actuated mechanism wound up, only by hand.

ОД 110/600 isolating switch (Fig. 106). The unit is an РДЗ(Д 110/600 isolator fitted with extra closing springs.

The switch is operated by a ПГ-10-О automatic mechanism incorporating an automatic trip. When closed, the switch, with its opening springs wound up, is held in this position by the operating mechanism. As the trip coil of the operating mechanism functions to release its free-trip device, the isolating switch is opened by the opening springs. The switch is closed by hand using a removable handle.

Mounting of a short-circuiting switch and its operating mechanism. The supporting surface for a short-circuiting switch is levelled in the same manner as for an isolator. The

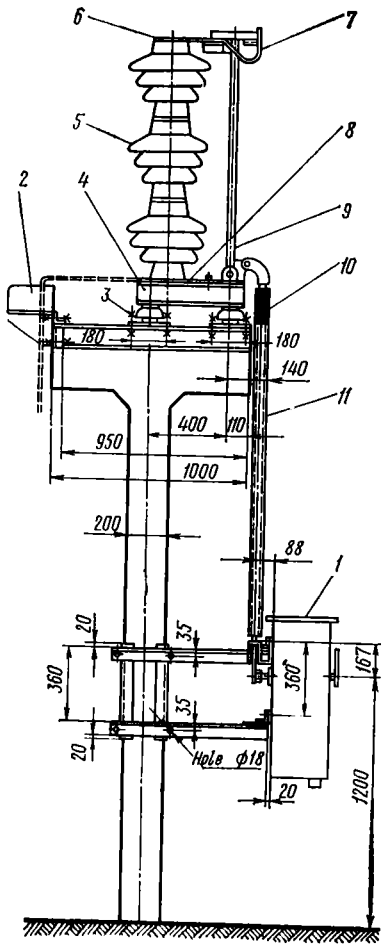


Fig. 105. K3-110 short-circuiting switch and its operating mechanism mounted on metalwork

unit is lifted onto the supporting structure by a crane and secured in place on four support insulators.

In setting up and fixing the short-circuiting switch, one must see that the blade correctly enters the fixed contacts. If it does not, the base of the switch has been deformed.

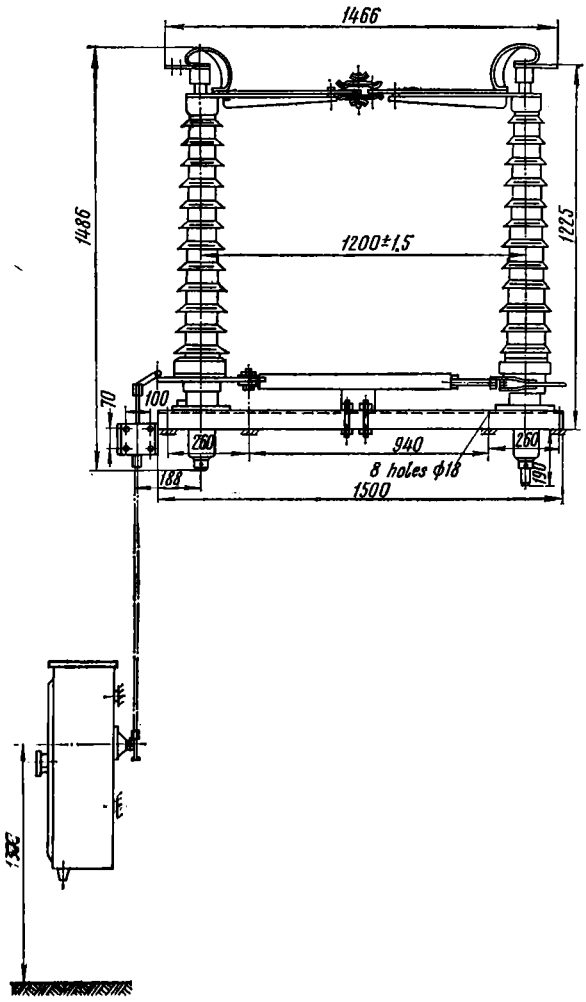


Fig. 106. ОД-110/600 isolating switch

Special care is required in pulling back the blade which is being forced by its spring to re-enter the fixed contacts.

A ПГ-10-К operating mechanism is secured on a metalwork and then wound up to match the open position of the short-circuiting switch. The latter is coupled to the operating mechanism by a tie rod of 1-inch pipe fastened to the lever that is fitted on the output shaft of the operating mechanism and pinned in place. The tie rod is fitted with the insert of rigid PVC furnished by the manufacturer.

A ТШЛО-5 current transformer is secured with four M12 bolts, whereupon an earthing busbar is passed through its window to complete the earth connection for the contact blade of the short-circuiting switch. When the short-circuit current is small (under 500 A), the busbar is substituted by a wire repeatedly passed through the transformer window, keeping in mind that from 500 to 800 primary ampere-turns should be provided if relay *3* (see Fig. 104) of the isolating switch is to give proper service.

Mounting of an isolating switch and its operating mechanism. Prior to mounting an isolating switch, the supporting surface should be thoroughly levelled using a batten. Small misalignment can be remedied by placing steel shims under the switch.

The three-single-pole units are lifted onto the supporting structure and combined into a three-pole set following the same procedure as in mounting a two-column isolator. The isolating switch should then be closed by hand to see that the centre lines of the contact blades are 5 mm beyond the longitudinal axes of their respective poles. The position of the blades can be corrected, if necessary, by adjusting the length of the in-pole link rods.

Once the isolating switch is levelled, plumbed, and finally secured in place, the operating mechanism and the intermediate linkage are installed and coupled by a tie rod of 1-inch steel pipe. The tie rod is fitted with the end fittings supplied by the manufacturer and coupled to the shaft of the operating mechanism by means of a lever fastened on the shaft with a taper pin. The linkage of the system can be adjusted by varying the length of both the in-pole link rods and the outer tie rods. Each single-pole unit of the isolating switch should be checked for contact pressure in the

same manner as those of a two-column isolator. For a male blade to be pulled out of the mating female blade, a force of at least 16 to 18 kg must be required. Contact pressure can be adjusted by tightening the bolts of the finger contacts.

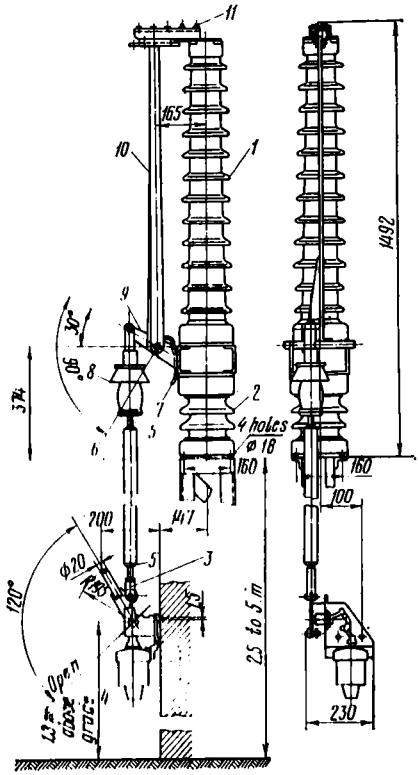


Fig. 107. 3OH-110 earthing switch

All rubbing parts of the linkage should be given a coat of grease mixed with 10 per cent (by weight) of graphite. Contact elements are for the most part lubricated with petroleum jelly.

3OH-110 single-pole outdoor earthing switch (Fig. 107). The switch is designed to earth the neutral of a power trans-

former. Its position in a circuit is shown in Fig. 104. The earthing switch comprises insulator *1* of the CT-110 type supporting fixed terminal *11* used to connect the supply line. Hinged to bell-crank *9* located at the base of the switch and extended outwards is moving blade *10* connected to earth by flexible link *7*. The base of the ЗОН-110 is additional insulator *2* of the КО-10 type secured on two channels.

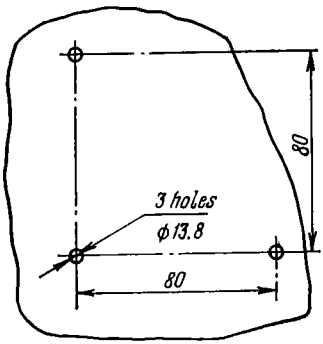


Fig. 108. Bolt-hole layout for mounting ПРН-10 operating mechanism

The earthing switch is operated by mechanism *4* of the ПРН-10 type. The switch and its operating mechanism are coupled by tubular tie rod *6* and insulating porcelain link *8*.

With a power transformer that is not protected against earth leakage, a second modification of the ЗОН-110 is used. This modification lacking insulator *2* and link *8* is also employed to earth busbars in outdoor switchgear installations.

An earthing switch is mounted on a supporting structure similar to those arranged for short-circuiting switches. The unit is lifted in place by a truck crane, secured with four M16 bolts, plumbed, and levelled. Fig. 108 presents a layout of holes for three M12 bolts used to secure the operating mechanism.

Tie rod *6* (see Fig. 107) has inserts *5* pinned or welded on both ends at the time of installation. The threaded end fitting of the upper insert is screwed into the metal portion of porcelain link *8*, and clevis *3* of the lower insert is attached to operating mechanism *4*. To facilitate the operation, a

1-inch steel pipe 250 to 300 mm long is fitted over the control lever of the operating mechanism.

The rubbing parts of the linkage and contact elements are coated with grease of the kind applied to isolators.

21. Mounting of Oil Circuit Breakers in Outdoor Substations

Outdoor substations employ C-35 and BMK-35 oil circuit breakers for 35-kV service and MKP-110M and BMP-110 oil circuit breakers for 110-kV service. The C-35 and the

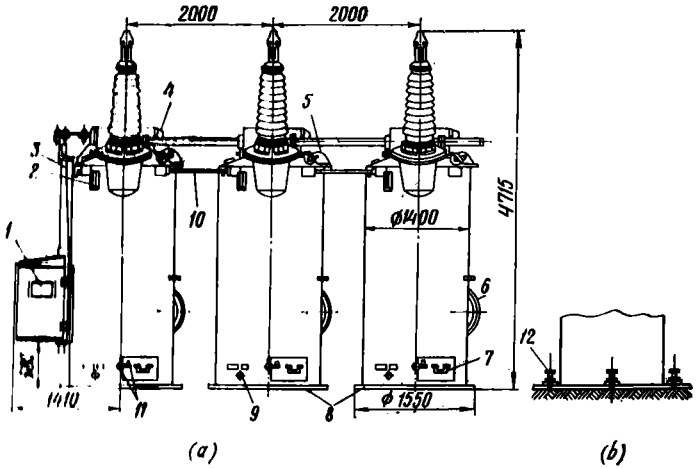


Fig. 109. MKP-110 oil circuit breaker

(*a*) general view; (*b*) breaker base; *1*—PRB-33 operating mechanism; *2*—oil gauge glass; *3*—tie rod; *4*—gas vent; *5*—relief valve; *6*—manhole for access to tank interior; *7*—manhole for access to tank underside; *8*—steel baseplate; *9*—earthing bolt; *10*—intertank connectors; *11*—oil drain cock; *12*—adjusting bolts

MKP-110M are bulk-oil units, and the BMK-35 and the BMP-110 are small-oil volume column-type circuit breakers.

Considered below is the mounting procedure for an MKP-110M circuit breaker. The MKP-110M is a 110-kV multitank, substation bulk-oil modernized circuit breaker.

Design. The mounting dimensions of the circuit breaker are given in Fig. 109, its interior arrangement in Figs 110 and 111.

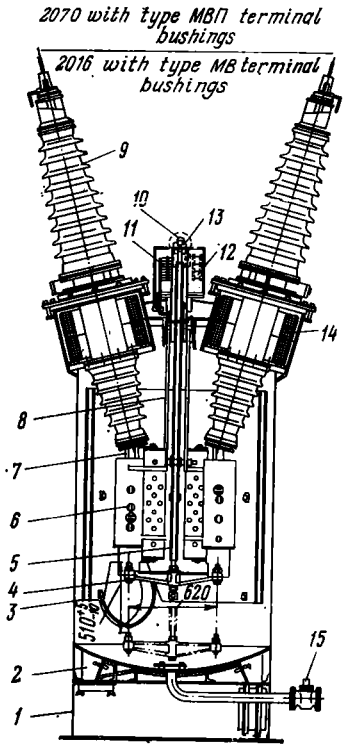


Fig. 110. Section through one phase assembly of МКП-110М circuit breaker

1—tank; *2*—oil heater; *3*—tank insulation; *4*—moving contact cross-arm; *5*—insulating lift rod; *6*—arc-control unit; *7*—contact rod; *8*—guide; *9*—terminal bushing; *10*—stop screw; *11*—terminals to connect leads from current transformer; *12*—actuating linkage; *13*—cap; *14*—bushing-type current transformer; *15*—oil drain cock

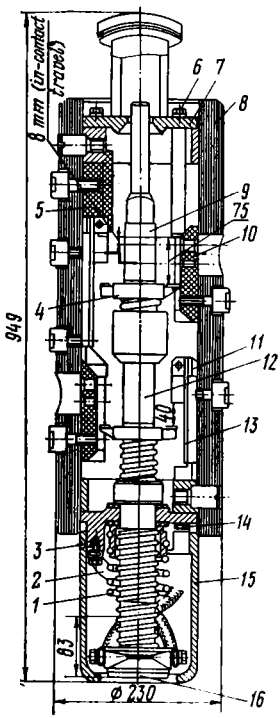


Fig. 111. Arc-control unit of МКП-110М circuit breaker

1—spring; *2*—flexible lead; *3*—screw; *4*—jumper; *5*—insulating block of upper fixed contact; *6* and *14*—bolts; *7*—cover; *8*—cylinder of phenolic resin plastic; *9*—moving insulating rod; *10*—discharge openings; *11*—fixed contacts; *12*—contact rod; *13*—insulating block; *15*—shield; *16*—lower contact

In this circuit breaker the arc is extinguished as follows (Fig. 112). Arcing contacts *5* and *3* part at the instant the breaker is opened. The intense heat of the arcs drawn across contacts *5* decomposes the oil, generating a gas whose high

pressure produces a flow of fresh fluid through the arcs that strike between contacts *3* opposite the discharge openings *4* of the arc-control chamber and then decay for the said reason. Once the current is interrupted and the arc extinguished in the arc-control chamber, a like process will take place in the external circuit, between contacts *7* and *8*. The

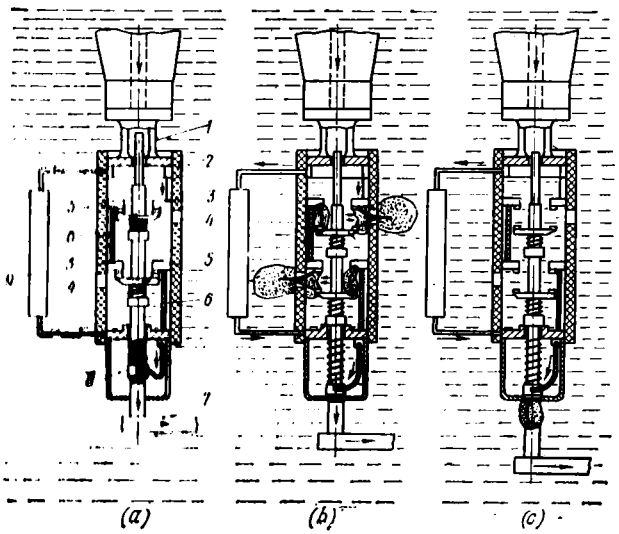


Fig. 112. Arc extinction in arc-control chamber of МКП-110М circuit breaker

(*a*) closed position; (*b*) and (*c*) in process of opening; *1*—holder; *2*—cylinder of phenolic resin plastic; *3*—arcing contacts; *4*—discharge openings; *5*—gas-generating contacts; *6*—jumpers; *7* and *8*—contacts; *9*—shunting resistor

extinction of the arc striking across these contacts requires no special arc-control device, since the resulting current is restricted to a low level by shunting resistor *9*.

The mass of the circuit breaker (without terminal bushings and oil) is 9 830 kg. The breaker takes 8 500 kg of oil.

This type of circuit breaker is available for three-phase and single-phase control and comes complete with a ШПЭ-33 solenoid type operating mechanism of 595-kg mass.

Inspection. An МКП-110М circuit breaker received for installation should be inspected for damaged crating and

packing boxes and for missing parts against the attached packing lists. Only the breaker tanks may be left outdoors; all the other parts should be kept in a heated room at a temperature of no less than +5°C.

Before installation, the circuit breaker should be visually inspected for damaged assemblies and parts, and thorougly cleaned of the deposit of dust accumulated in transit.

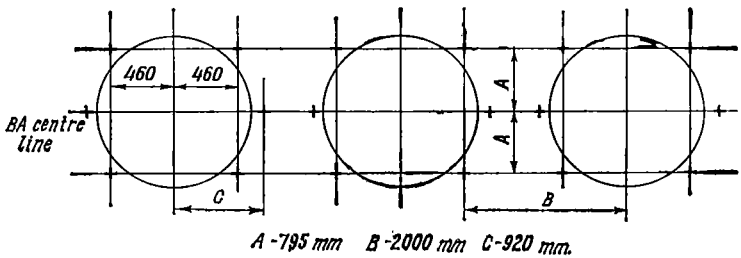


Fig. 113. Layout of anchor bolts for MKII-110M circuit breaker

Mounting and assembly. The circuit breaker is brought to its foundation on a flatcar, or on a truck riding a rail track, or on a suitable sledge.

Figure 113 shows the layout of the anchor bolts in the breaker foundation. The phase assemblies of the circuit breaker are placed on the foundation by a truck crane.

The breaker tanks should be located on the foundation according to the markings on the tanks and on the levers of the operating mechanism. Once the tanks of the three phase assemblies are in place, they are levelled and aligned on the foundation. To accomplish this, hoods *3* (Fig. 114) are removed from the actuating linkage housings, a steel wire is strung along the centre line of the three phase assemblies, and the tanks are levelled and aligned so that the centre line of each housing coincides with the steel wire. The distance between the phase assemblies is also checked. For greater stability, pads of boiler steel 8 to 10 mm thick are slipped under the tank feet.

The breaker is levelled and aligned using adjusting bolts *12* (see Fig. 109*b*) and secured to the foundation with six anchor bolts (not shown in the figure).

The phase assemblies are connected into a three-pole unit by means of right-and-left threaded couplers *4* (Fig. 115), tie rods *6*, and actuating levers *9*. The end fitting of the tie rod must be screwed at least 20 mm into the coupler. To start with, the first and second poles, and next the second

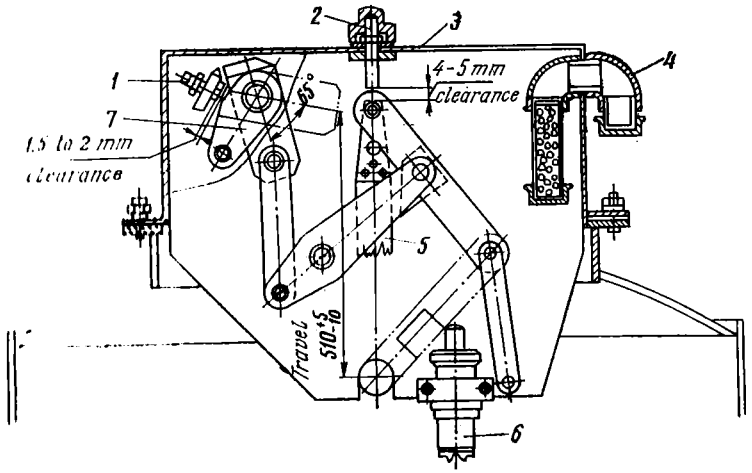


Fig. 114. Actuating linkage

1 and *2*—stop bolts; *3*—hood; *4*—gas vent; *5*—insulating lift rod; *6*—oil dashpot; *7*—actuating lever (Ref. No. 9 in Fig. 115)

and third ones, are joined together. Each of the three phase assemblies is coupled to operating mechanism *1* (see Fig. 109) by tie rod *3*.

Prior to installing the current transformers (Fig. 116), they should be checked as discussed above. Next the bottom and walls of the current transformer chamber are lined with oil resistant rubber. Each current transformer is lifted by a truck crane using the hoisting device shown in Fig. 117. The current transformer is secured in place with wooden wedges, and its leads are given servings of herringbone or taffeta tape.

The current transformers are followed by the bushings (Fig. 118*a*) which are also first inspected for broken porcelain, cemented joints, and damaged current-conducting ter-

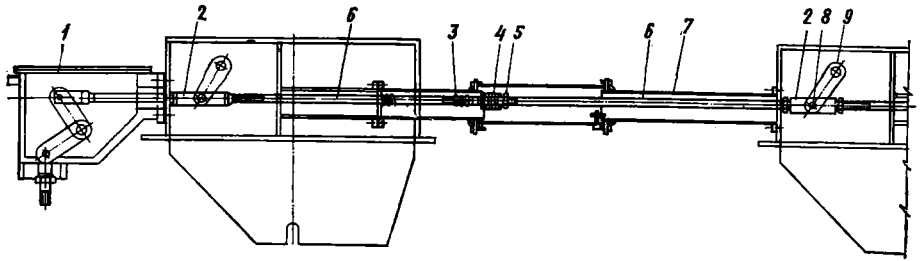


Fig. 115. External actuating linkage of circuit breaker

1—angle housing with position indicator; *2*—jaw; *3*—opening spring; *4*—coupler; *5*—lock nut; *6*—tie rod; *7*—housing; *8*—pivot; *9*—actuating lever (Ref. No. 7 in Fig. 114)

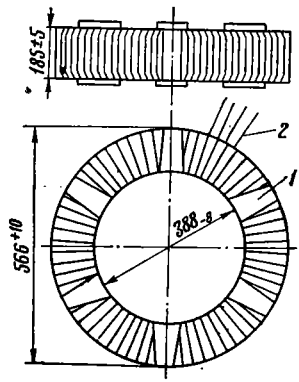


Fig. 116. Bushing-type current transformer
1 wedge; *2*—leads

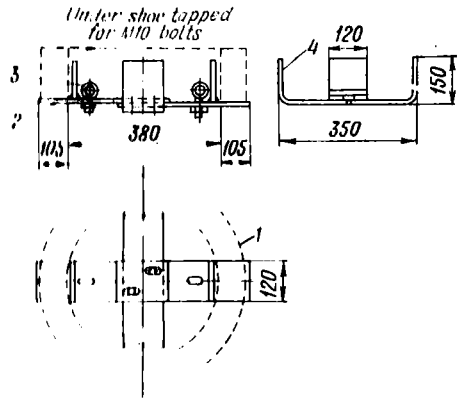


Fig. 117. Device for hoisting of current transformer
1 transformer; *2* plate; *3*—lifting ring; *4*—shoe

minute. The bushings should be subjected to an electrical test.

To install a bushing, it should be suspended from the hook of a truck crane as shown in Fig. 118*b*. When lifting, tackle block *3* should be operated to tilt the bushing at about 15° to the vertical so as to position it for mounting on the breaker cover. The bushing should be inclined towards breather *1* (see Fig. 118*a*) and the sludge plug located in the flange of the expansion chamber at the top of the bushing.

In mounting a bushing, care should be taken not to damage the tank lining with porcelain shell. Should the shell touch the top sheet of the tank lining, the latter has to be trimmed to allow a clearance of 20 to 30 mm between it and the porcelain shell. The tilt of the bushing is then pre-

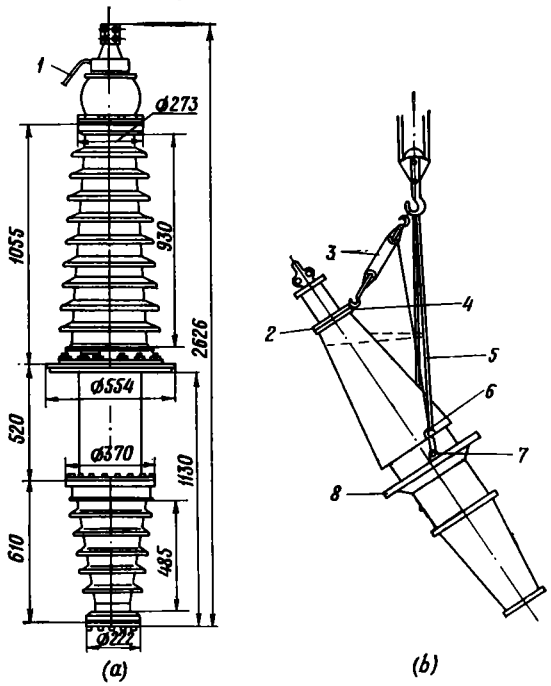


Fig. 118. Terminal bushing (*a*) and arrangement of hoisting tackle (*b*)
1—breather; *2*—clamp; *3*—tackle block; *4*—clamp eye; *5*—sling; *6*—hook; *7*—lifting ring; *8*—holder

adjusted by loosening or tightening the fastening nuts. The tilt is finally adjusted, and the nuts tightened, at the time of final adjustment of the circuit breaker.

In transit, the breather hole at the top of the bushing must be closed with a screw and washer which are subsequently removed and replaced by the breather, with its hole facing downwards.

The bushings are followed by the arc-control chambers which should first be thoroughly inspected. To do this, cap screws *3* (see Fig. 111) are withdrawn, shields *15* removed, bolts *14* unscrewed, and the contact assembly taken out for examination. Dust, if any, should be blown out of the cham-

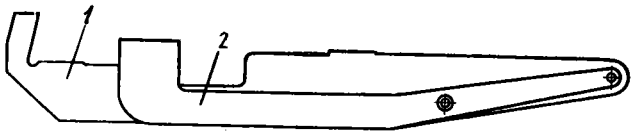


Fig. 119. Template for adjustment of actuating linkage
1 template; *2*– template indicator

ber with compressed air or removed with a clean dry rag. Minor defects on the insulating parts can be remedied by cleaning and then coating with oil varnish.

As the contact rod is moving in the chamber, movable copper flexible leads *2* fitted on the rod must follow it readily, without jamming.

To inspect the shunting resistors, first the contact leads are disconnected and the end cover of the protective case removed. Then the inner cylinder carrying the resistance coil is taken out and examined for breaks, shorted turns, and reliable contact at the connections. Shorted turns, if any, must be separated by about 0.8 mm. Next the shunt is assembled and checked for its resistance, which should be 780 to 770Ω as measured with a direct current instrument, such as the Wheatstone bridge.

Adjustment of the operating mechanism and contact system. The operating mechanism is adjusted by means of interlink tie rods *6* (see Fig. 115) and their couplers *4*. For initial adjustment, the moving contacts secured on cross-arms *4* (see Fig. 110) should be fully lowered. With the circuit breaker closed (using a jack), the moving contacts must not actuate the contact assembly of the arc-control chamber. The distance between lever *9* (see Fig. 115) and stop bolt *1* (see Fig. 114) should be adjusted to 1.5 to 2 mm. The circuit breaker is then checked for the dead-centre position against a template (Fig. 119). When properly adjusted

(Fig. 120), the middle pivot of the three forming a dead centre in the actuating linkage of each pole is about 2 mm beyond the dead-centre position.

Next the contact cross-arm is lowered through 83 mm from the closed position, and a pencil mark is made on its lift

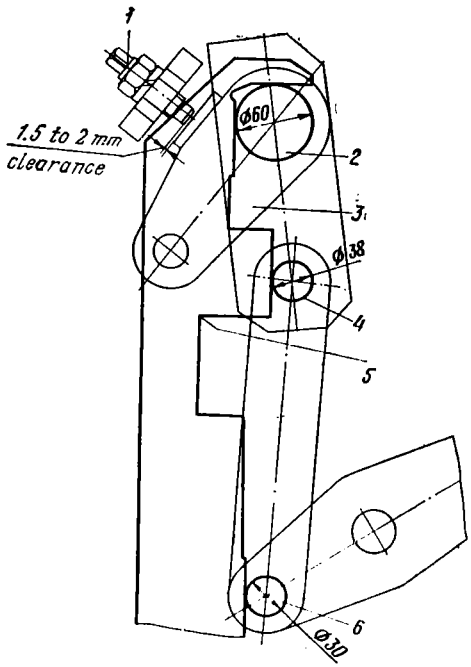


Fig. 120. Checking of MKII-110M circuit-breaker actuating linkage against template

1—stop bolt; *2*—main shaft of actuating linkage; *3*—actuating level; *4*—middle pivot; *5*—template; *6*—lower pivot

rod level with the bottom end of guide *8* (see Fig. 110). The nuts fastening the moving contacts on the cross-arm are then slackened, and these contacts are fixed in such a position that they touch the outer contacts of the arc-control chambers. In the process, the contacts of the chambers and the moving contacts of the cross-arm should be checked for proper alignment.

With the breaker in the closed position, the actuating linkage is again checked for proper position against the template. Now the middle pivot must be at most 2 mm short of the dead-centre position, but never beyond it. The required adjustments are done using intertank tie rods *6* (see Fig. 115) and couplers *4*.

In the course of adjustment use is made of the mechanical diagram given in Fig. 121. Prior to adjustment, dashpots *6*

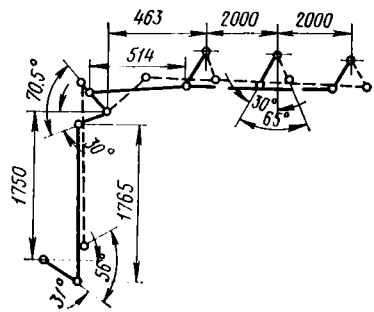
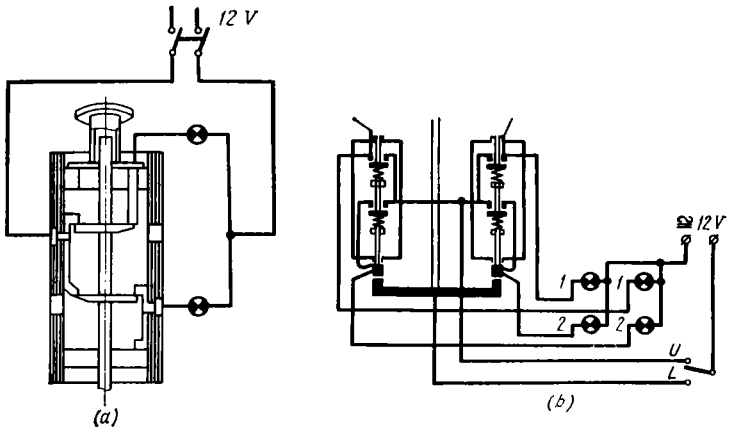


Fig. 121. Linkage coupling operating mechanism to MKII-110M circuit breaker. Mechanical diagram

(see Fig. 114) of the actuating linkage are filled with oil. Once the actuating linkage has been adjusted, couplers *4* (see Fig. 115) must be firmly secured in place.

The circuit arrangement diagrammed in Fig. 122*a* enables the contacts of an arc-control chamber to be checked, before installation, for simultaneous closure. The maximum tolerable difference specified by the manufacturer is 1 mm.

To adjust the travel of the contacts of a phase assembly and to check them for simultaneous closing and parting, use is made of the circuit arrangement diagrammed in Fig. 122*b*. With the switch of the test circuit in the lower position *L*, lamps *2* will light up at the instant the moving contacts touch the lower contacts of the arc-control chambers. Once the switch is flipped to the upper position *U*, lamps *1* and *2* will come on as soon as the inner contacts close up. After these lamps have lighted up, the cross arm must travel 11 ± 0.5 mm till the breaker is fully closed. The contacts are adjusted for proper travel and synchronous closure by repositioning the moving contacts.



For. 122. Test circuits for adjustment of breaker contacts
(*a*) in one arc-control chamber; (*b*) in one phase assembly

From the instant the moving contacts touch the lower contacts of the arc-control chambers till the full closure of the breaker, the rods of the arc-control chambers must travel 83 mm as checked against the earlier made pencil mark. The breaker cross-arm must travel a total of 510 $\pm$0.2 mm from the closed position. To check the cross-arm travel, a pencil mark is made on the lift rod level with the bottom end of guide *8* (see Fig. 110) when the breaker is closed. The breaker is then opened, and a second mark is made, with the cross-arm in the lower position. The distance between the two marks will give the total travel of the cross-arm.

Manhole *6* (see Fig. 109) provides access to the interior of the tank. The bottom of the tank is covered with boards upon which a knock-down ladder is set up. While work is done in the tank, safety bolt *5* (Fig. 123) of the operating mechanism must be screwed in to prevent an accidental closure of the breaker.

On completion of adjustment, a check should be made on springs *3* (see Fig. 115) of the actuating linkage, the loaded length of which must be 292 mm apiece.

Trial closings of the circuit breaker and filling it with oil. Once the erection gang are sure to have left the tanks, safety

bolt *5* (see Fig. 123) of the operating mechanism should be removed. Next the dry circuit breaker is given a number of trial closings.

On completion of this operation, safety bolt *5* is screwed in again, and the control circuit is broken by removing the

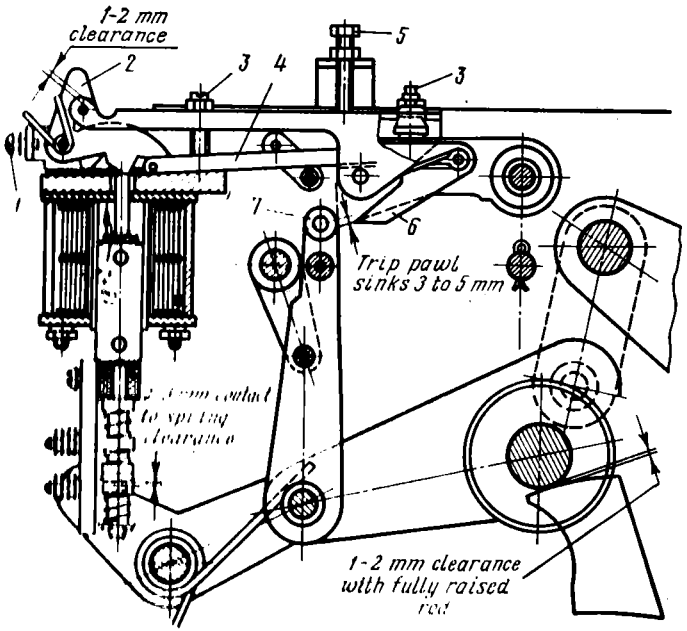


Fig. 123. Adjustment of operating mechanism

1—adjusting screw; 2—latch; 3—adjusting screws; 4—lever; 5—safety bolt (to be screwed out on completion of installation and adjustment); 6—trip pawl; 7—free-trip device roller

associated fuses, whereupon the bolted joints within the tanks are tightened.

Prior to filling the breaker with oil, the resistance of its contacts should be measured, along with their make and break time, and the circuit breaker should be subjected to all kinds of tests performed by adjusting crews. The internal parts should be wiped with clean lint-free rags. The oil drain

pipe and its cock *15* (see Fig. 110) should be cleaned by flushing with oil. The insulation of the tanks and other parts should be dried using blowers or the heater provided within the circuit breaker.

The breaker is filled with dry, clean transformer oil, checking its level by the oil gauge glass.

A newly introduced advanced method is to deliver the tanks of 110-kV circuit breakers with the current transformers in place and the circuitry properly connected, which facilitates the installation and wiring of substation equipment. What is more circuit breakers are supplied complete with suspended scaffolds.

22. Mounting of Air-Blast Circuit Breakers in Outdoor Substations

Supply and distribution of compressed air. Modern substations make good use of air-blast circuit breakers which are flame- and explosion-proof and quick of response, with their contacts rather little affected by spark-wear on interruption of short-circuit currents.

The circuit breakers employ compressed air produced by compressor plants for the dual purpose of extinguishing the arc and actuating the contact system. The compressed air is stored in air receivers to be delivered into the air-distributing network of the substation.

The main piece of equipment interposed between the compressor plant and circuit breaker is the distributor cabinet. Considered below is the design of a ШРНФ-2 distributor cabinet intended for outdoor installation and provided with a filter.

The pneumatic circuit of the cabinet incorporates stop valve *1* (Fig. 124) enabling the air supply to the circuit breaker to be turned on or off. To clean the supplied air of solid particles, the cabinet is fitted with a filter the main component of which is cartridge *9*. The metal shell of the cartridge is filled with horse-hair and felt. The changeable cartridge is reusable on cleaning. To take it out for cleaning, first the air flow should be turned off by closing stop valve *1* and then release valve *2* opened to let the air out of the filter.

Reducing valve *4* serves to reduce the pressure of the

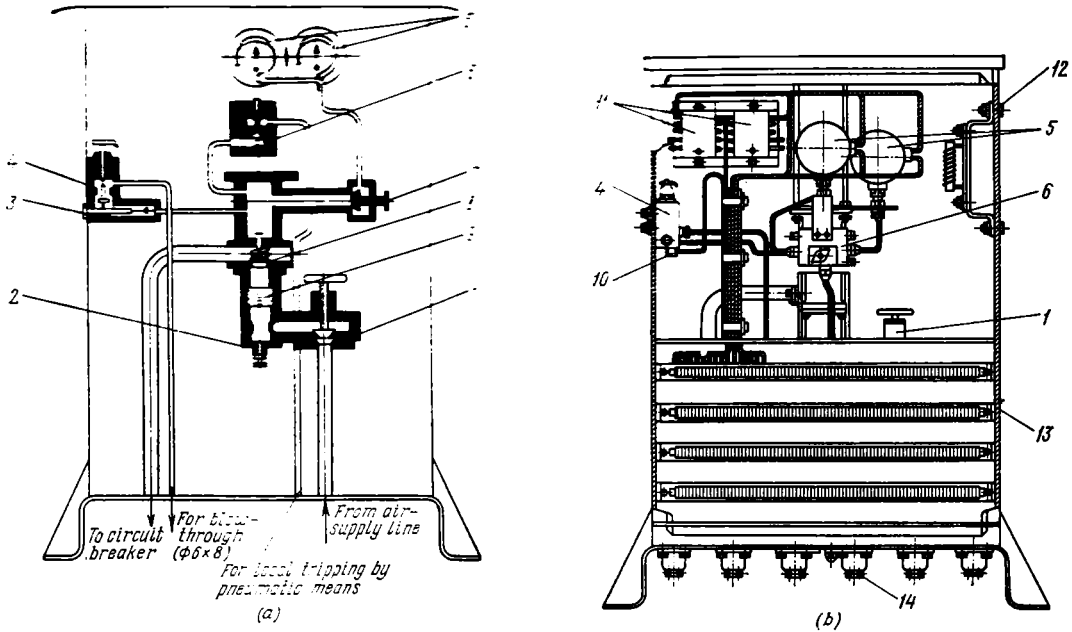


Fig. 124. ШРНФ-2 distributor cabinet
(*a*) pneumatic circuit; (*b*) front view (without doors)

air supplied for blowing out (ventilating) the interior of the circuit breaker. Shut-off valve *3* enables the reducing valve to be removed, if required, without releasing the air from the air receiver of the circuit breaker. The circuit breaker can be locally controlled by pneumatic means from push-button station *6*. Should the supply line be damaged, check valve *8* will prevent the air from flowing out of the air receiver of the circuit breaker.

The cabinet has built-in electric contact pressure gauges indicating the air pressure in the supply line. In the event of an impermissible pressure drop the pressure gauges will actuate relays *11*, thus breaking the control circuits lest the circuit breaker should be closed. The flow of compressed air to the pressure gauges can be interrupted by closing stop valve *7*. If the ambient air temperature falls below 5°C, electric heaters *10* and *12* will be turned on to heat the pressure gauges and reducing valve *4*.

The control cable is terminated in cable shoes *14*, with the cable conductors connected to terminal blocks *13*.

Mounting of a BBH-110 air-blast circuit breaker with an air-break isolating switch (Fig. 125). The base of each phase assembly of the breaker is air receiver *1* arranged on top of which are support insulators *4* and *10* carrying arc interrupter unit *6* and air-break isolating switch *9*, respectively. Compressed air from receiver *1* is fed to the arc interrupter unit through blast valve *2* and to the isolating switch through blast valve *11*. The function of valves *14* on the underside of the receiver, at both its ends, is to let the compressed air out. To keep check on the ventilation of the breaker interior, use is made of air-delivery indicator *13*. Cabinet *3* at the centre of the base contains the components of the pneumatic and electric control systems.

Line terminals L_1 and L_2, intended to connect the substation buses, are joined to each other via the contact systems of the arc interrupter unit and isolating switch interconnected by tubular busbar *5*.

Cabinet *16* distributes the compressed air among the three phase assemblies of the circuit breaker. The design of the distributor cabinet has been discussed above.

The three phase assemblies of the breaker have a total mass of about 8 000 kg.

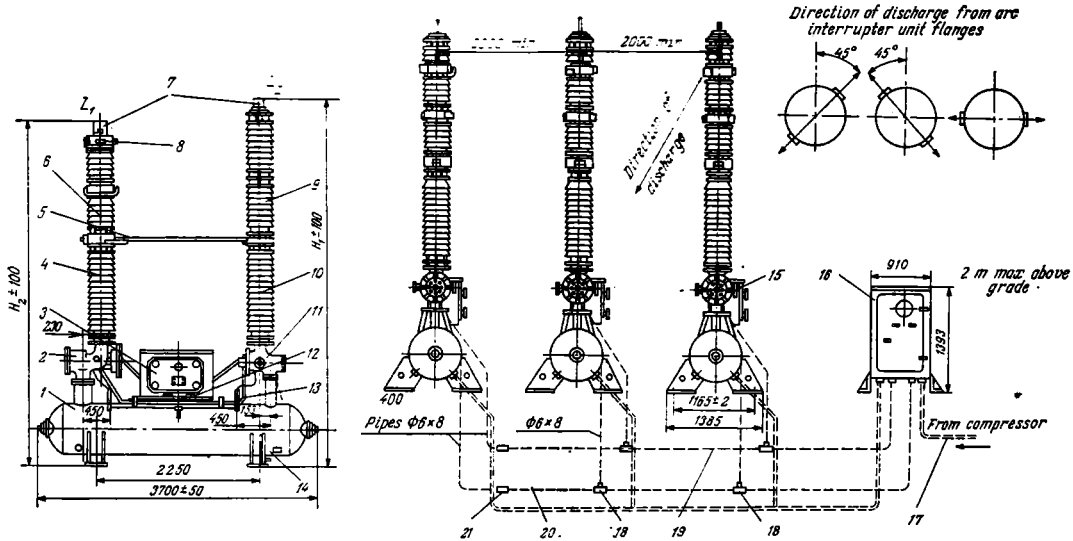


Fig. 125. BBH-110 air-blast circuit breaker with air-break isolating switch

1—air receiver; *2*—blast valve of arc interrupter unit; *3*—control cabinet; *4*—support insulator of arc interrupter unit; *5*—tubular busbars; *6*—arc interrupter unit; *7*—line terminals (L_1 and L_2); *8*—frames for lifting arc interrupter unit; *9*—isolating switch; *10*—support insulator of isolating switch; *11*—blast valve of isolating switch; *12*—cable shoes; *13*—air-delivery indicator; *14*—release valve; *15*—breaker position indicating lamps (may be relocated to the other side of cabinet); *16*—distributor cabinet; *17*—main blast line (25 mm dia); *18*—reducing tees; *19* and *20*—air supply pipes; *21*—reducing nipples

Mounting of the circuit breaker. Described below is the procedure to be followed in erecting the phase assemblies. The base of a phase assembly, i.e. its air receiver, should be set upon a specially prepared foundation, levelled using a batten and level, and then secured in place with eight M30 bolts. Misalignment, if any, can be eliminated by inserting pads of boiler steel 5 to 8 mm thick where necessary.

Once the air receiver is bolted down, its end covers should be removed to examine the interior. If any damage to the factory-applied coating or traces of corrosion are detected, the affected spots must be cleaned with a steel-wire brush, degreased with petrol, and coated with a mixture of minium and drying oil. The coated spots are allowed to dry, whereupon the end covers are re-installed and bolted in place.

The end-caps should be removed from the flanges of blast valves *2* and *11*, along with the side covers, and all the accessible parts of the valves wiped clean and greased. The flanges should be wiped with clean rags.

The cover of control cabinet *3* should be opened, and the grease changed in the valves of the enclosed units and in the СВК operating mechanism. The shut-off valve should be flushed with petrol and left ungreased. The closing and opening electromagnets should be examined, along with their interlock contacts, and the latter wiped clean. The distance between the strikers of the electromagnets and the associated valves should be checked. The striker of an electromagnet must travel 8 mm and make the local control valve cover the full length of its stroke. The interlock contacts of the electromagnets must enter their companion contacts as far as 1 mm.

While inspecting the control cabinet, all the copper pipes of the pneumatic control system should be cleaned and blown through.

Release valves *14* on the underside of the air receiver should be examined, wiped, and greased anew. Next air-delivery indicators *13* are installed.

Prior to mounting the support insulators, they should be thoroughly wiped on the inside with a clean cloth of calico or coarse calico soaked in petrol. The cloth is wound on a smooth-planed wooden stick to form a "doughnut".

All the butt joints of the support insulators (and subse-

quently those of the arc interrupter units) should be packed with rubber gaskets bonded to the porcelain with Grade 88 adhesive. The surfaces to be bonded are first sanded. The rubber must have a low-gloss surface free of reticulations. The surfaces are wiped with a clean cloth of calico or coarse calico moistened with aviation spirit or alcohol and then given a thin coat of premixed adhesive, which is allowed to dry for 5-6 minutes at 20°C, whereupon another coat of adhesive is applied.

The support insulators should be mounted in place with a truck crane using a general-purpose sling to suspend them from the crane hook. The arc interrupter unit should be set on the support insulators so that its deflectors guiding the exhaust flow are properly positioned.

When mounting the isolating switch, its contact parts are connected to those of the arc interrupter unit by a copper tube attached to the flanges of the support insulator stacks with clamps supplied by the manufacturer. The ends of the tube may be cut to size on the spot, if required.

In mounting the phase assemblies of the circuit breaker, care must be taken to keep out moisture, dust, etc. With this aim in view, a boarding should be erected at the installation site and topped with a makeshift shelter so constructed that a portion of its roof can be hinged open. All the preparatory operations should be carried out within the enclosed space, whereupon a truck crane should be used to take the specific parts out through the opening in the roof and mount them in place. Such parts as the support insulators, arc interrupter units, and the like should be wrapped up in a piece of varnished cloth and a tarpaulin before they are moved.

All the moving parts, except the shut-off valve stem, should be wiped with rags moistened in petrol or white spirit to remove the slushing compound and then given a thin coat of grease, the grade being recommended by the manufacturer.

The support insulators must be brought in register, and their porcelain parts kept out of contact with metal. The bolts of the butt joints should be tightened by giving their nuts a quarter of a turn at a time as a maximum.

In the course of assembly attention should be paid to the

markings of specific parts having the following four characters stamped on in a rectangle: the pole number, the letter П (the first letter of the Russian term for "pole"), the letter В (the first letter of the Russian term for "circuit breaker"), and the circuit breaker number, e.g., 2ПВ2 stands for the second pole of the No. 2 circuit breaker.

The assembly procedure set forth above is to be followed provided a period of no longer than 12 months has passed since the circuit breaker was delivered by the manufacturer and it has been kept in a closed room throughout this period. This assembly procedure is also acceptable if the circuit breaker has been in storage for 6 months and the manufacturer's requirements specified in the list of standard equipment have been complied with. According to these requirements some of the parts (such as the truck, distributor cabinet, support insulators) may be stored outdoors in their crating, while other parts (such as the arc interrupter unit and the isolating switch chamber) should be kept in their packages under a shed, and small spare parts in a closed room.

Otherwise, the circuit breaker must be given a strip inspection before installation in compliance with the manufacturer's instructions.

23. Mounting of ТФН Instrument Current Transformers

Outdoor substations employ ТФН instrument current transformers. The overall and mounting dimensions of the ТФНД-35М and ТФНД-110М transformers are given in Figs 126 and 127, respectively. In the type designations the letter Ф stands for "porcelain-insulated", О for "outdoor", М for "modernized", and the letter Д denotes that the transformer has secondary windings designed to energize the circuits of a balanced protective system. The mass of the first type of transformer is about 270 kg, and that of the second type is up to 700 kg.

In transit the current transformer must stand upright to within 15 degrees.

Once on the site, the current transformer should be unpacked and wiped, first with rags moistened with petrol and then with a clean dry cloth. At the same time it should be

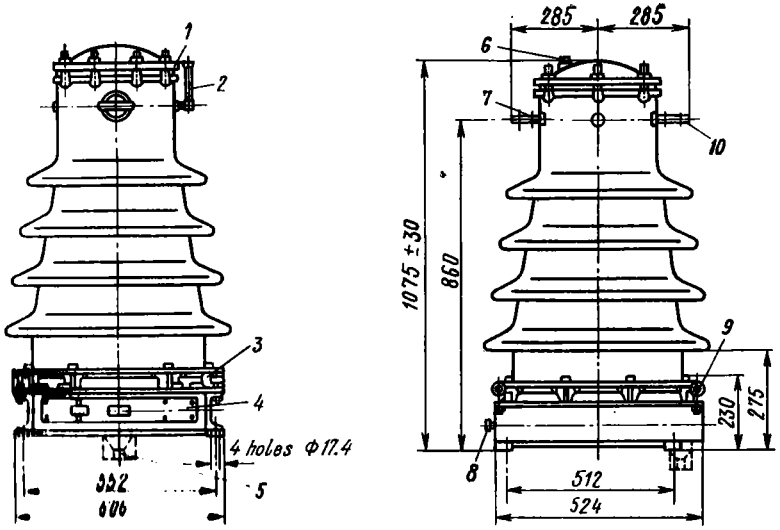


Fig. 126. ТФНД-35М current transformer

1—cover to oil gauge electric connection; *2*—oil gauge glass; *3*—nameplates; *4*—secondary winding terminal box; *5*—cable shoe; *6*—breather valve; *7* and *10*—primary winding terminals; *8*—oil drain fitting; *9*—eyebolt

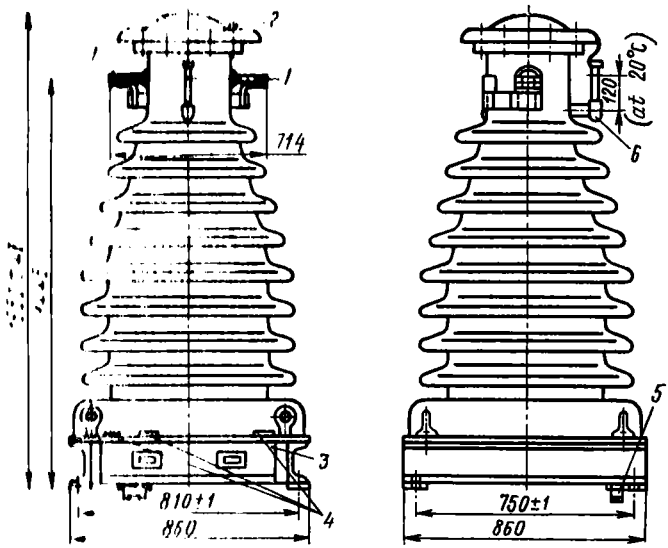


Fig. 127. ТФНД-110М current transformer

1—primary winding terminals; *2*—breather valve; *3*—secondary-winding terminal box; *4*—nameplates; *5*—cable shoe; *6*—oil gauge glass

examined for broken porcelain or oil gauge glass, oil level, and for missing parts and nameplate.

The current transformer is lifted in place by a truck crane. The hoisting slings are attached to the four eyebolts on the base. It is good practice to wrap a rope 40 to 50 mm in diameter round the upper fins of the insulator to prevent the porcelain from being damaged by the slings.

Most current transformers of the ТФН type are mounted on metal or reinforced-concrete supports and secured with M18 or M20 bolts.

The base of the transformer should be earthed by connecting the earthing busbar to the bolt marked "3".

24. Mounting of НОМ-35 and НКФ-110 Instrument Voltage Transformers

Voltage transformers НОМ-35 (single-phase) and НКФ-110 (cascade, porcelain-insulated) are designed for use in outdoor substations of the 35-kV and 110-kV classes.

The main overall dimensions of these transformers are given in Figs 128 and 129*a*. The mass of the НОМ-35 transformer is 248 kg, including 75 kg of oil, and that of the НКФ-110 is 875 kg, including 140 kg of oil.

As may be seen from the schematic diagram of the НКФ transformer (Fig. 129*b*), it is made up of two series-connected coils inserted between the live line and earth. The voltage across either of the coils is $1/2V_{ph}$ (phase voltage), which makes them easier to insulate. The centre taps of the coils are connected to the core, and hence the voltage applied to the outermost turns is as low as $1/4V_{ph}$, which further facilitates the task of insulation. The insulation of the cores is rated above $1/2V_{ph}$. The core of the lower of the cascaded coils usually carries two secondary windings intended to connect instruments and relays.

Prior to mounting in an outdoor substation, voltage transformers should be externally and internally inspected, for which purpose the cores are taken out.

НОМ-35 voltage transformers are mounted on metal or reinforced-concrete supports and secured with M16 bolts. НКФ-110 voltage transformers are mounted on similar supports and secured with M20 bolts or braced in place. Trans-

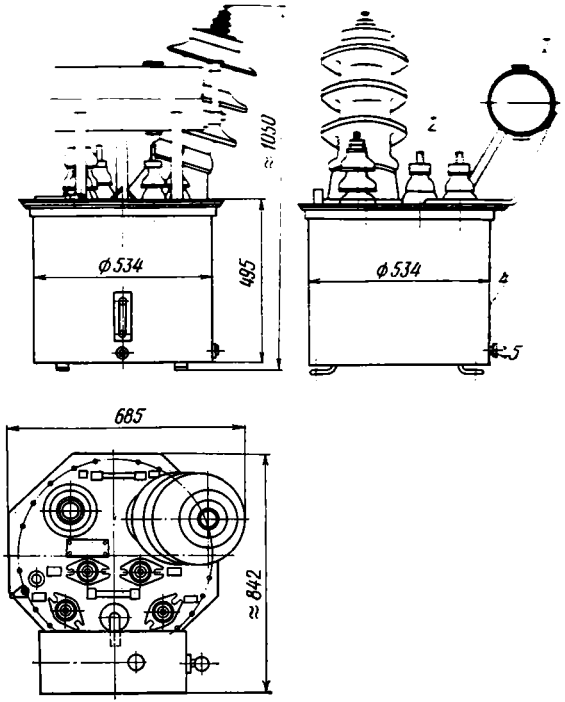


Fig. 128. HOM-35 voltage transformer

1—high-voltage terminal; *2*—low-voltage terminal; *3*—oil conservator; *4*—tank; *5*—oil drain cock

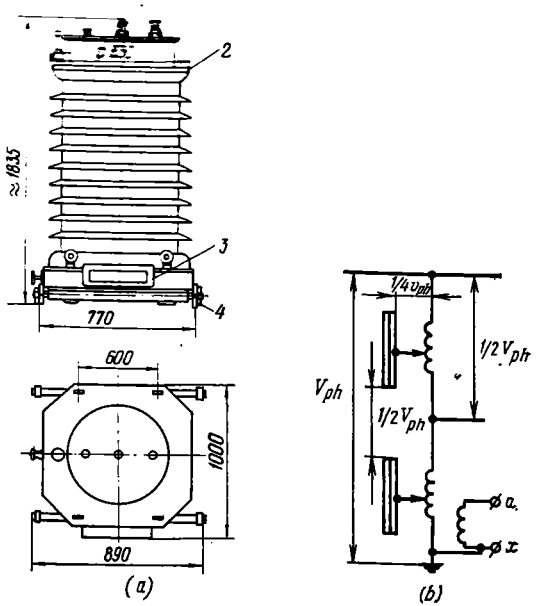


Fig. 129. НКФ-110 voltage transformer

(*a*) design; (*b*) schematic diagram; *1*—terminal for connection to high voltage; *2*—porcelain shell; *3*—low-voltage winding terminals; *4*—rollers

formers are lifted into position by a truck crane using the hoisting rings provided on the base or the hooks welded to the tank.

When voltage transformers are being moved about, they should be held upright to within 30 degrees off the vertical.

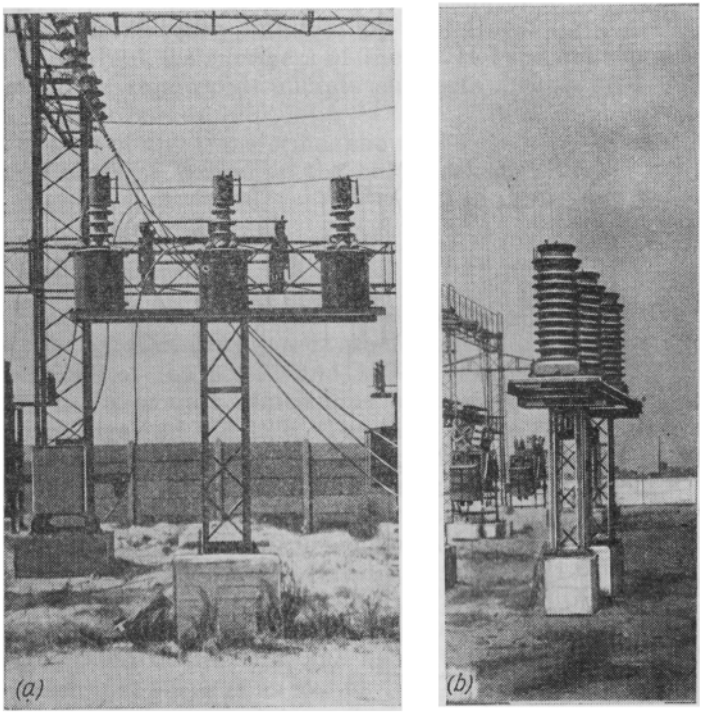


Fig. 130. Voltage transformers installed in outdoor substation
(*a*) НОМ-35 transformers; (*b*) НКФ-110 transformers

Figure 130 depicts the НОМ-35 and НКФ-110 voltage transformers installed in an outdoor substation.

25. Mounting of Reactors and Lightning Arresters

Mounting of reactors. Cast-in-concrete reactors can be installed in outdoor substations. Reactor columns are built into brickwork or concrete kiosks where the same installa-

tion procedure is followed as in indoor substations. Use is also made of oil-filled reactors.

Mounting of lightning arresters. Outdoor substations for 35 and 110-kV service employ РВП-35 valve-type substation lightning arresters and РВС-110 valve-type main station

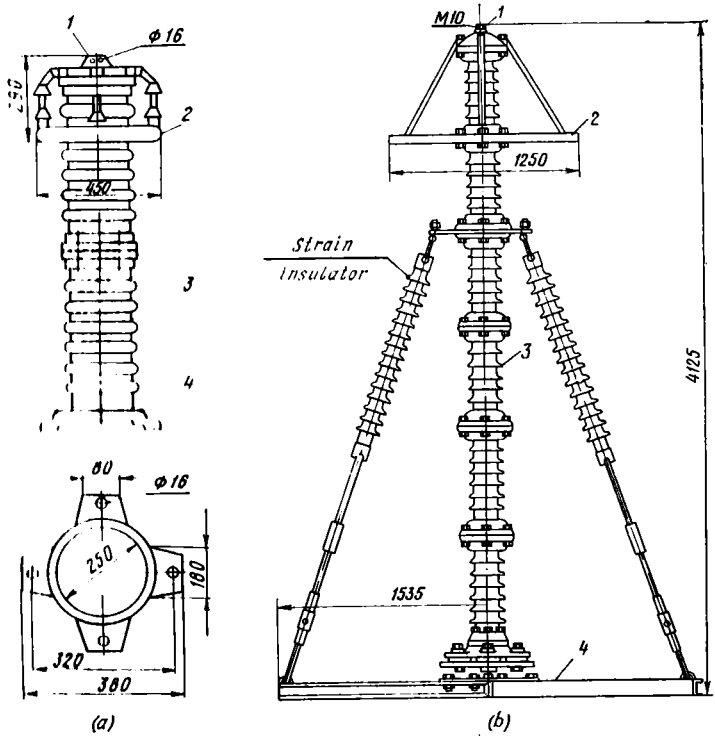


Fig. 131. Valve-type lightning arresters

(a) РВП-35; (b) РВС-110; *1*—screw terminal for connection to line; *2*—shielding ring; *3*—porcelain shell; *4*—base

lightning arresters. Their mounting dimensions are given in Fig. 131. The mass of the РВП-35 lightning arrester is 70 kg, and that of the РВС-110 is 230 kg.

Considered below by way of illustration is the installation procedure for РВС-110 lightning arresters which is essen-

tially the same as that for РВП-35 lightning arresters. First the support or foundation is plumbed and levelled. Then the arrester elements are matched according to the marking (*1-1*, *2-2*, *3-3*) on their flanges, their contact surfaces are cleaned, and the elements are assembled into stacks which are subsequently brought into vertical alignment. Misalignment, if any, is remedied by inserting steel shims under the bottom flanges. The joints at the flanges are given a coat of phenol-formaldehyde lacquer or glyceryl-phthalate varnish.

When mounting a lightning arrester, extreme care must be exercised in tightening the bolts on the flanges of the separate elements, proceeding from one bolt to another round the circumference and giving each nut a quarter of a turn at a time as a maximum. Uneven tightening of the bolts may crack or break the porcelain. The bolts should have spring washers to take up the stress generated by the tightening. Once a stack is assembled, the joints at the flanges are given another two or three coats of moisture-proof varnish for air-tightness.

26. Installation of Outdoor Buses

The bus systems of outdoor switchgear are mainly made up of aluminium and aluminium steel-cored cables carried by strings of suspension insulators. Suspension insulators are assembled into strings to suit the operating voltage of the installation. Thus a string for 35 kV will consist of two or three units, and for 110 kV, of six to eight units. Strings of insulators are strung with the aid of suitable links and clamps. An example of their use is given in Fig. 132.

Before a string of insulators is assembled, the insulators should be thoroughly inspected and wiped clean. If the porcelain is found to be defective (have chipped spots, scratches on the glazing, cracks, unglazed spots), the insulator must be rejected. Assembled strings of insulators are laid out at the supports from which they are to be suspended.

A bus system is installed as follows. Once the strings of suspension insulators are assembled and brought to their sites, the bus cable is run out, for which purpose the cable drum is lifted with jacks placed under a spindle passed through the drum. This can also be done on a suitable tres-

tle. Should the cable come in coils, as sometimes is the case, it is uncoiled using conventional payoff stands.

After the cable has been run out, its end is secured in the clamp of the outermost support, the length of the cable on either side of the clamp being specified in the installation drawing in compliance with the scheme of connections adopted for the outdoor substation section involved. The cable

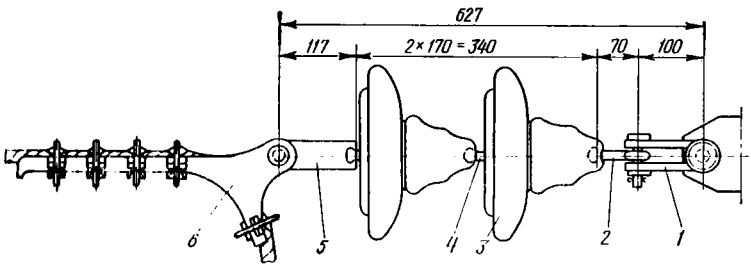


Fig. 132. Tension insulator string

1 —shackle for attaching to support cross-arm; *2*—ball-eye fitting; *3*—insulator; *4* —pin; *5*—socket-eye fitting; *6*—bolted-type tension clamp

end to be fixed in the clamp should be first served with a strip (1 mm by 30 mm) of the same metal as the outer lay of the cable. This precaution is necessary to avoid injury to the wires of the cable. The cable terminated in the clamp is attached to a tension insulator string, and the assembly is lifted onto the support by means of a rope and block secured to the support cross-arm. The cable is then strung to the second support by tackle blocks or a winch over a snatch block attached to the support. The cable is fastened to the tackle block or winch with a wedge- or bolted-type clamp (Fig. 133).

The cable must be tensioned as specified in the design. The tension may be determined by placing a dynamometer between the cable and the tackle block or winch. The sag of the cable may be found by sighting.

The tight cable is marked with a binding of soft wire where the insulator string is to be attached to the support. The cable is then lowered to the ground for the length of the string to be laid off from the wire mark (towards the interior

of the span), a tension clamp is installed at this point and fastened to the string, whereupon the whole assembly is lifted onto the support by means of a rope and block and secured in place.

The other two phase conductors are strung in the same way and adjusted for sag by arranging them parallel to the first phase conductor.

Tee-offs are connected to the apparatus with bolted- or compression-type clamps or by welding.

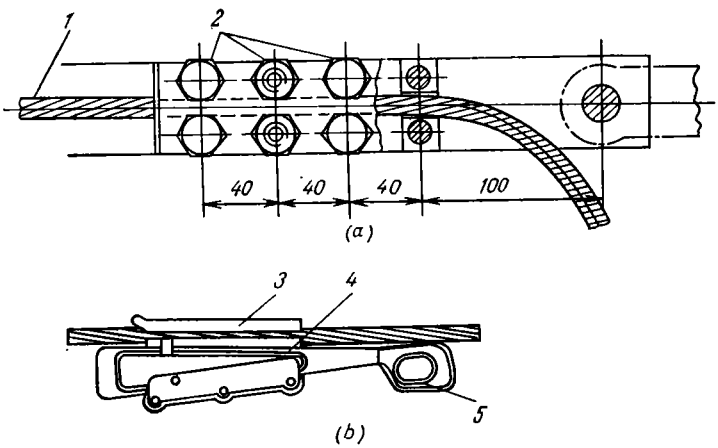


Fig. 133. Stringing clamps

(*a*) bolted-type; (*b*) wedge-type; *1*—conductor; *2*—bolts; *3*—body and cover plate; *4*—underplate; *5*—wedge

Sometimes the relative positions of the apparatus and supports make it advisable to use steel rods by means of which a tension insulator string can be moved as far as needed.

As a good practice, collecting bus cables intended for outdoor switchgear, are fabricated to templates complete with tee-offs for apparatus, in a workshop. Now instrumental survey is being integrated into installation practices with the aim to measure the length of the cables used as buses in outdoor substations so that specific sections and assemblies of bus systems can be subsequently fabricated in a workshop.

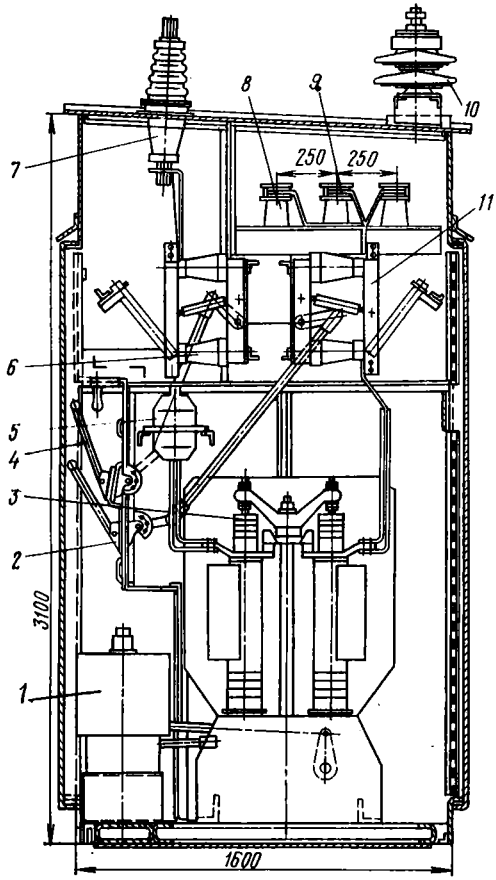


Fig. 134. Series K-VII outdoor-type КРУН unit

27. Installation of Factory-Assembled Outdoor Switchgear. Summary

The design of a КРУН factory-assembled outdoor switchgear unit is illustrated in Fig. 134. The unit incorporates МГГ-10/500 oil circuit breaker *3* with ПЭ-2 operating mechanism *1*. The unit accommodates bus isolator *11* and line isolator *6* operated by mechanisms *2* and *4*, respectively,

and employs ТПШЛ bushing-type current transformers *5*. Collecting buses *9* arranged in a separate compartment are carried by support insulators *8*. Bushing *7* and support insulator *10* serve to connect the busbars of an outdoor substation. This type of switchgear unit has no roll-out truck. Since the unit is designed for outdoor installation, its doors are provided with sealing gaskets.

КРУН units are mounted on their supports using a truck crane. Once they have been lined up along a cord strung for the purpose, plumbed, and levelled, each of the units is secured to its bed frame, whereupon the isolators and circuit breaker are to be adjusted, as are their operating mechanisms.

At present it is recommended that the equipment installed in factory-assembled switchgear units be fully adjusted in a workshop before they are forwarded to the erection site.

Problems

1. Write up the mounting of three ИШД-35 insulators on a bridge-type busbar structure depicted in Fig. 97, and list the required tools and fixtures.
2. Write up a sequence card for mounting an РЛНД2-35/1000 isolator complete with its ПРНЗ operating mechanism on the metalwork of an outdoor substation, as shown in Fig. 101.
3. Write up a sequence card for mounting an МКП-110 oil circuit breaker complete with its operating mechanism in an outdoor substation.
4. Write up the mounting of a ВВН-110 air-blast circuit breaker complete with a ШРНФ-2 distributor cabinet in an outdoor substation.
5. Make up a list of tools, fixtures, and devices required for mounting three ТФН-110 curren \-transformers on the metalwork of an outdoor substation.
6. Write up a sequence of operations for mounting three НКФ-110 voltage transformers on the metalwork of an outdoor substation.
7. Write up the assembly of the elements of an РВС-110 lightning arrester in a stack, and specify the required tools.

CHAPTER 4

Installation of Power Transformers

28. Delivery of Transformers to the Site

Low-power transformers are shipped to the site completely assembled, and medium-power transformers, either completely assembled or with some of the parts (conservators, vent pipes, etc.) dismantled and packed in boxes.

All transformers from 110 kV upwards are, as a rule, delivered partly dismantled, with their radiators, high-voltage bushings, oil conservators, vent pipes, and air blast system separately packed.

Low- and medium-power transformers are transported to the site on trucks or carriers, and high-power transformers, by rail, on suitable flatcars (Fig. 135).

The simplest and most convenient way to unload transformers is by cranes. The truck, carrier, or flatcar with a transformer is driven under the hook of a crane, all the bracings, stop blocks, and wire guys used to secure the transformer in transit removed, the hoisting slings attached, and the transformer lifted and moved onto a specially prepared unloading platform.

Where the truck or carrier can be brought up right to an unloading platform that is level with the truck (carrier) bed, the transformer can be unloaded using a winch and wire ropes. If there is a difference in floor elevation, the unloaded transformer is placed on a cage built up of railway sleepers and held together by cramp irons (Fig. 136).

When a transformer is moved with the use of a winch and wire ropes either rails or steel strips must be put under its rollers.

From the cage of a transformer is lowered down a ramp built of railway sleepers, timbers, and boards. A transformer can be most conveniently brought to the site on a truck riding a rail track.

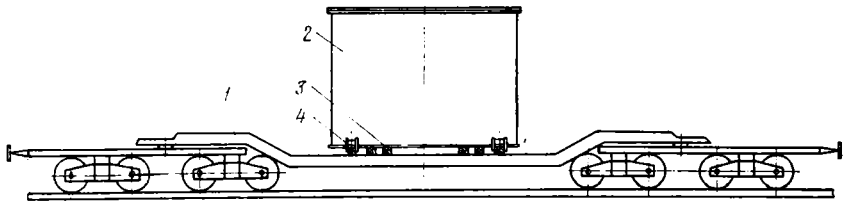


Fig. 135. Power transformer secured on railroad flatcar

1—flatcar; *2*—transformer; *3*—rest bar; *4*—C-clamp

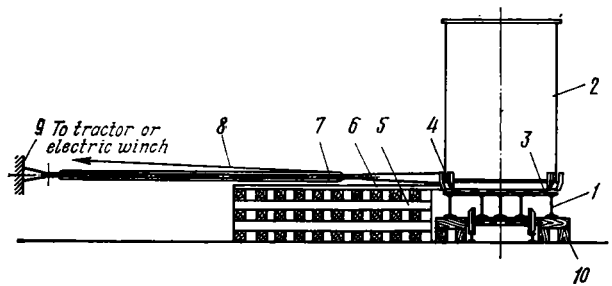


Fig. 136. Transformer unloading

1—carrier; *2*—transformer; *3*—length of board; *4*—bracket for jacks; *5*—cage formed by railway sleepers; *6*—rails; *7*—block; *8*—steel wire rope; *9*—anchor; *10*—railway sleepers

29. Mounting of Transformer Parts

Mounting of radiators. Before mounting a transformer radiator on the transformer housing, it should be pressure-tested and flushed out.

A pressure test has to be conducted in order to make sure that the radiator tubes are intact. The test pressure is usually built up by a column of oil poured into a pipe attached to one of the radiator flanges. The height of the oil column is made equal to the distance from the lowest point of the radiator mounted in place to the top of the oil conservator, plus 0.5 metre. Should any defects be detected in the radiator during the test, they are rectified by electric or gas welding. Radiators are flushed with clean and dry transformer oil.

The first step in mounting a radiator is a check to see that the radiator cocks on the transformer tank are turned fully off. Then the blind flanges are taken off the outlets to receive the radiators and their flanges thoroughly cleaned.

The radiator can now be suspended by its stirrup, and its upper flange can be bolted to its companion cock flange. A 10 mm thick gasket of oil-resistant rubber somewhat exceeding the cock outlet in inside diameter shall be inserted between the flanges. The lower radiator and mating cock flanges are then joined in the same manner, and the bolts coupling the upper and lower flanges are tightened.

When a transformer has no radiator cocks, one of the access covers on its tank top should be removed, the oil drained until it is level with the upper radiator flanges, and the radiators matched to the latter. The oil is next drained to below the lower radiator flanges, the radiators are finally secured in place, and oil immediately poured in the transformer level with the upper yoke.

Mounting of bushings. On removal from its packing box, a terminal bushing should be cleaned of all packing material and dirt and wiped clean, first with a rag moistened with petrol and then with a rag moistened with transformer oil. The bushing should be visually inspected to see that the oil level is sufficiently high and its porcelain and glass parts

are intact. If some 10 per cent of the oil has leaked out of the bushing, the oil level should be topped up prior to mounting on the transformer.

Before the bushing is mounted, the oil level in the transformer must be brought down to the upper yoke (without, however, exposing the yoke insulation) by opening the radiator cocks to admit some of the oil into the radiators. If the resulting oil level is not low enough, the excess oil should be drained.

The blind flanges used for transportation are removed in turn from each of the openings to receive the bushings, and new gaskets of oil-resistant rubber are put in place. Next each bushing is suspended by the hoisting rings (eyes) on its base flange, slowly lowered in contact with the rubber gasket, and secured by uniformly tightening the nuts round the circumference. The top terminal cap is now removed from the installed bushing, a length of wire or rope is passed through the central tube, the contact stud soldered to the end of the cable lead is then tied to the wire or rope and pulled up through the central tube. The stud is fixed in place with a steel pin and the top terminal cap is screwed on. The next operation is to examine, clean, and mount the low-voltage, bushings. They should be mounted on gaskets of oil-resistant rubber in the same manner as the high-voltage bushings.

Mounting of oil conservator and Buchholz relay. First the remaining oil should be drained from the conservator (Fig. 137) by removing plug *6* of sludge sump *5*, the conservator flushed with clean and dry transformer oil, and the oil gauge glass and the connection cock mounted in place. The conservator may be placed for the time being on two brackets secured to the transformer cover.

Next the elbow is removed from the pipe connection between the shell and the conservator and replaced by the Buchholz relay, taking care to position properly its sight glass. The position of the relay should be checked with a level. Then the paper pads inserted for transit are removed from under the floats in the relay, and the floats are arranged so that the arrow on the cover of the assembly points in the direction of oil flow to the oil conservator. It must be remembered that the sealed joints of the relay should not

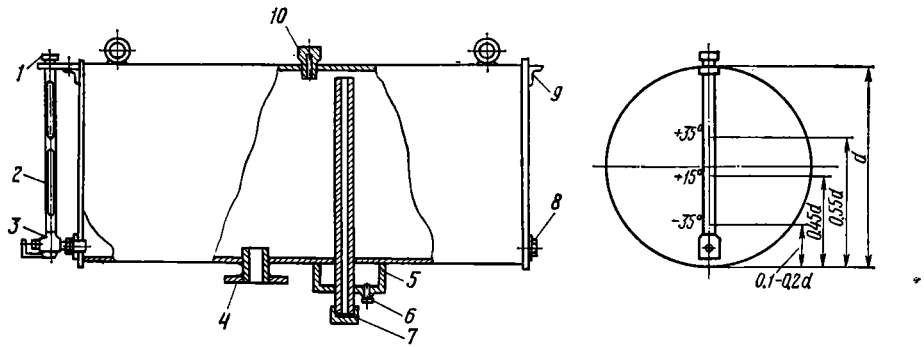


Fig. 137. Power-transformer oil conservator

1—oil-gauge cap; *2*—oil-gauge glass; *3*—oil-gauge body; *4*—pipe connection; *5*—sludge sump; *6*—sump drain plug; *7*—breather plug; *8*—plug; *9*—angle; *10*—oil-filling plug (*d*—conservator diameter)

be taken apart in the course of installation, for they have been factory-tested for oil tightness.

For easy passage of the gases underneath the transformer cover to the Buchholz relay, the transformer should be slightly raised (about 10 mm) at the side where the oil pipe is connected to the conservator. The oil pipe should, in turn, have a slope of at least 2 per cent. What is more, the oil pipe should not have any bends, pockets, or reversed slope which would trap gas bubbles.

The conservator should be so mounted that the lowest possible oil level in the oil gauge glass is somewhat above the upper cock of the Buchholz relay. Once the Buchholz relay and the oil pipe have been installed, the conservator straps are finally tightened.

Mounting of vent pipe and fittings. First the blind flanges are removed from the transformer cover and from the upper and lower flanges of the vent pipe which is then cleaned and flushed with oil, a glass disk is secured on its upper flange, gaskets of oil-resistant rubber are placed on the transformer cover and topped with the vent pipe attached to the conservator with a brace. In so doing it should be checked that the vent pipe is provided with the air-bleeder plug.

Next the thermometers are put in place according to the installation sketch. They may be of the mercury-bulb, mercury-contact, remote-indicating Bourdon-tube, or remote-indicating switchboard type. Before installing the thermometers, the screw plugs are removed from the transformer cover and replaced by the thermometer pocket fittings screwed in place. The space between the thermometer pocket driven into the transformer cover and a mercury-contact or mercury-bulb thermometer should be filled with oil.

30. Filling of Transformer with Oil and Putting into Operation

The oil to be filled or added into a transformer on the site must be checked for compliance with all the requirements of the relevant standard.

The oil is poured through the access hole. Alternatively, the access cover can be closed and properly sealed, and the oil poured through the 2-inch cock on the transformer cover

or through the oil conservator. The temperature difference between the oil being poured in and that already in the transformer must not exceed 5 deg. C.

When the oil becomes level with the cover, the remaining amount is poured through the oil conservator, with the cock connecting the latter to the transformer tank opened so as to let out a weak stream of oil and thus avoid the ingress of excess air into the tank.

Before the transformer is finally topped up, the air-bleeder plugs should be unscrewed on all the oil-filled bushings in order to release the air. As soon as the oil starts running out through the air-bleeder openings, the plugs should be screwed back in place, with lead sealing washers placed under them. While filling up the transformer, the air-bleeder plugs should be removed from the vent pipe and from the welded flanges of the high-voltage bushings to let the air out. The upper cock on the Buchholz relay should also be periodically opened until a stream of oil appears. Oil filling is discontinued when the oil has risen to 30 or 40 mm above the reference line marked on the oil gauge glass of the conservator.

As noted above, the transformer should be slightly raised on the conservator side for proper operation of the Buchholz relay. For this purpose, steel strips are slipped, where necessary, under the wheels of the transformer truck.

While work is done on the transformer, great care must be taken to see that the erection crew have no tools beyond what is required for the job and carry nothing in the pockets of their overalls.

After or during the installation of the transformer, the signal lines are run to the Buchholz relay and the thermometers. If the transformer is installed indoors, the line conductors may be laid in rigid steel conduits using Grade ПР wire. For outdoor transformers, use is normally made of Grade КВВГ cable also laid in rigid steel conduits. The cross-sectional area of each wire or cable conductor must be at least 1.5 mm^2.

Once the transformer has been installed and put through all the required safety tests*, it is prepared for placing into

* A detailed discussion of power transformer testing will be found in the literature of the subject.

service. To do this, the cocks between the conservator and the tank are checked to see that they are open, as are the upper and lower radiator cocks, a final sample of oil is taken for a dielectric strength test, and the insulation resistance of the windings is measured.

When everything is in order, full voltage is applied to distribution and substation transformers at once. With large and also station coupling transformers, generators are normally used to raise the applied voltage gradually and in a smooth manner from zero to the test voltage specified in the manufacturer's instructions so that the turn-to-turn insulation can and should be tested.

In both cases, a steady humming, without loud buzzing or crackling, should be heard.

After a transformer has been tested under the rated voltage it should be left on at no-load for some time in order that the attending personnel and the erection crew can examine both the transformer and its connections. The transformer is then switched on and off several times in succession to make sure that the balanced protective system does not respond to the inrush of the magnetizing current.

Next the transformer is connected, on the secondary side, to the load. Before the voltage is first applied to a transformer, all its protective relays should be set for instantaneous tripping.

Questions and Problems

1. How are the radiators of power transformers mounted?
2. How are the terminal bushings of power transformers mounted?
3. How are the oil conservator and the Buchholz relay of a power transformer mounted?
4. Write up the procedure for filling a transformer with oil and putting it into operation.

CHAPTER 5

Installation of Protective Earthing Networks

31. Protective Earthing of Indoor Substations

The protective earthing network made up of earthing electrodes and earth-continuity conductors has the dual purpose of connecting all the bases and metal enclosures of the associated electrical equipment to earth so as to have them, for the sake of safety, at earth, i.e. zero, potential, and making the short-circuit current strong enough for positive action of relays and other protective gear.

The protective earthing network of an indoor substation is installed in two stages: first the buried outdoor grounding mat is installed and then the indoor earthing busbars (earth-continuity conductors) are arranged.

With the buried outdoor grounding mat, the initial step is to mark out and dig the trenches. The centre line of a trench should be at least 2 to 2.5 metres from the walls of buildings, the trench being 0.6 to 0.7 metre deep. The next step is to drive the earth electrodes into the soil. Steel rods of 12-mm diameter driven about 5 m deep into the soil have been found to be the most convenient form of earthing electrode. Earthing electrodes are driven into the soil with the use of a ПЗВ driver shown in Fig. 138. Steel angles 50 mm by 50 mm of 2.5- to 3-m length are also used as earthing electrodes. Electrodes of this type are driven into the soil with an electric vibrator or a truck-mounted auger fitted with an earth-rod driving attachment.

Both rods and steel angles are driven into the bottom of a trench until only ends 150 to 200 mm long stick out for the underground earth-continuity conductors to be welded to. The regular form of underground earth-continuity conductor is a steel strip 40 mm by 4 mm that is properly straightened, laid on edge in the trench, and secured to the extending ends of the earthing electrodes by clips first welded to the strip

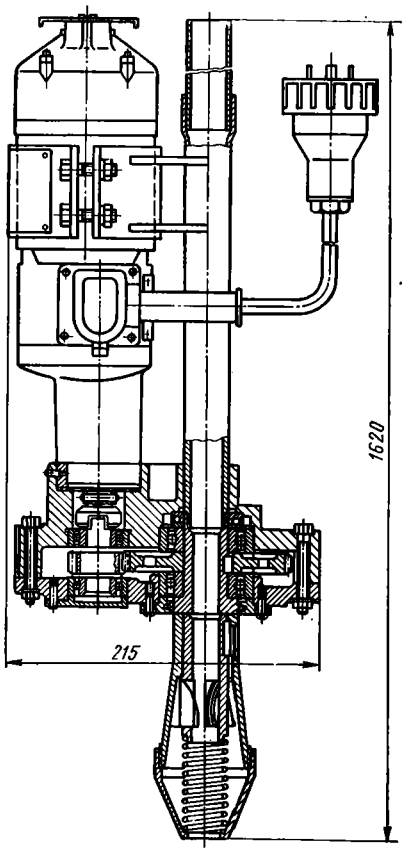


Fig. 138. ПЭВ earth-rod driver

and then to the electrodes. The welded joint between an earthing electrode and an earth-continuity conductor is tested for strength by striking with a sledge hammer of up to 2 kg in weight. Earth-continuity conductors are run into the switchgear structures through steel-pipe conduits.

With the outdoor grounding mat in place in the trenches, all its runs are drawn on a plan showing their position relative to the adjacent permanent structures, the trenches are backfilled, and the soil rammed in.

In current practice wide use is made of the underground structures, such as pipelines, foundations, etc., available on the site. They are tied into the main grounding mat along with the earthing electrodes.

Within switchgear structures the earthing busbars are carried by fastenings varying in shape depending on the prevailing conditions and location and secured to the walls and ceilings. The most advanced technique of fixing the earthing busbars involves the use of an CMII dowel-driving gun.

For earth-continuity conductors arranged indoors, the attachment points are spaced out 650 to 1 000 mm apart.

Where earth-continuity conductors cross temperature expansion joints, compensation bends must be provided. Where earth-continuity conductors pass through walls, they should be run through sleeves of steel pipe.

Joints and tee-offs on earth-continuity conductors are made by welding.

Runs of earth-continuity conductors to apparatus should be fastened by the earthing bolts provided on some pieces of equipment.

With apparatus mounted on metal supports, the earth-continuity conductors should be welded directly to the metalwork. The contact surfaces of the apparatus and the supports should be thoroughly cleaned and coated with petroleum jelly or cup grease.

The completed earthing network inside a substation is given a coat of black asphaltum varnish, while the places reserved for temporary earth connections should be left unpainted.

17. Protective Earthing of Outdoor Substations

The protective earthing network of an outdoor substation also consists of a main grounding mat which usually has the form of a ring encompassing the entire switchyard and earth-continuity conductors radiating from the main ring towards the respective pieces of equipment.

The main grounding mat of an outdoor substation does not differ in construction and installation procedure from the buried grounding mat of an indoor substation.

The earth-continuity conductors radiating from the main ring are generally laid in the cable ducts and welded to the parts embedded beforehand in the duct walls.

The earth-continuity conductors brought out to the earthed apparatus should be enclosed in sleeves of steel pipe as high as 1 to 1.5 m above ground.

Questions

1. What are the main elements that make up a protective earthing network?
2. What are earth electrodes made of and how are they driven into the soil?
3. What is the proper distance between earth electrodes and the walls of buildings and that between adjacent electrodes?
4. What are the existing methods for driving earth electrodes into the soil?
5. How are earth-continuity conductors connected to the earthing electrodes driven into the soil?
6. How is an indoor earthing network arranged?
7. What components of an electric installation are to be earthed, and what is the proper way of connecting a piece of equipment to the earthing network?

CHAPTER 6

Installation of Control Circuits

33. General

Control and secondary circuits form an integral part of modern station and substation switchgear and provide the means for performing such functions as control of the power or primary circuits, protection of the electrical equipment, measurement of the electrical quantities in the primary circuits, routine and alarm signalling, etc.

Control circuits are installed to the diagrams included in the design of a given installation; the diagrams employ standardized symbols to represent specific components of the control circuits and their interconnections.

Wiring diagrams. While installing control circuits, one is guided by the so-called wiring diagrams indicating the destination of each lead (cable or wire).

Figure 139 presents, by way of illustration, the wiring diagram for a voltage transformer installed in a 6-kV switchgear unit. As may be seen from the diagram, the secondary windings of the НТМИ-10 transformer and a terminal block are interconnected by a Grade КВРБГ control cable (*1*) 8 × 2.5 mm², and a Grade КВРБГ cable (*2*) 10 × 2.5 mm² is run from the terminal block to the KCA auxiliary contacts. The symbols employed in the diagram are both numerals and letters. The following designations are used: *A*, *B*, *C*—phases, their respective colour codes being yellow (*Y*), green (*G*), and red (*R*); *O*—neutral; *a*, *b*, *c*, *d*, *x*—terminals of transformer secondaries and the associated circuit designations on the KCA auxiliary contacts and the terminal block; *1ПР*, *2ПР*, *3ПР*, *4ПР*—fuse numbers; *1*, *2*, *3* through *12*—consecutive numbers of terminals in the terminal block.

Some of the designations on the terminal block are as follows:

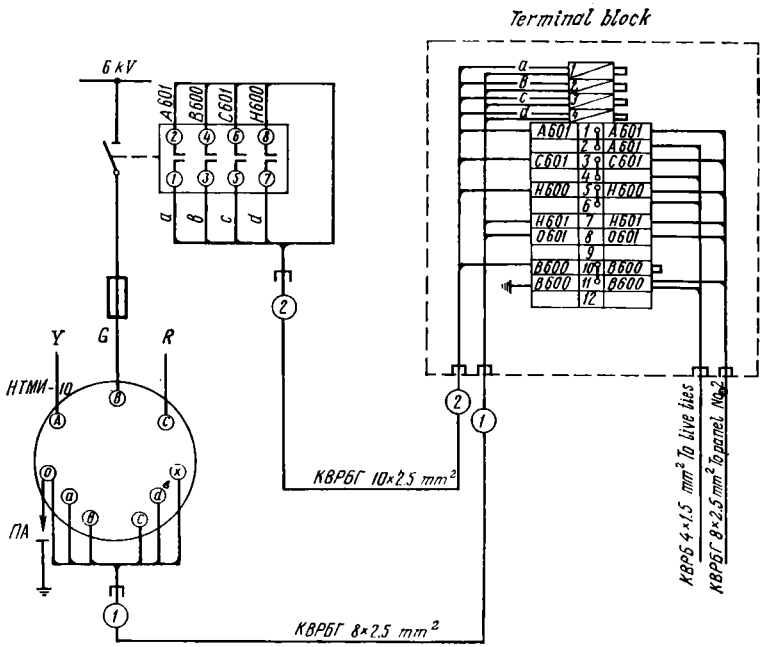


Fig. 139. Voltage-transformer wiring diagram

A601—circuits connected to the voltage between the phase *A* conductor and the neutral; *C601*—same for phase *C*; *B600*—same for phase *B* (these circuits are normally earthed);

H600 and *H601*—circuits connected to the windings of the voltage transformer that are used in testing the power circuit for insulation resistance.

The terminal *a* of the transformer secondary is connected to earth via a ПА automatic air-break cutoff whose function is to protect the unit against lightning surges. The automatic cutout features an air gap that breaks down when acted on by a lightning surge, which provides a discharge path to earth for the transformer secondary.

Breakdown schematic diagrams. A presentation of the element-by-element relationship of specific components of

control circuits is given in the so-called breakdown schematic diagrams. The simplest type of breakdown schematic diagram is exemplified in Fig. 140 depicting the circuit controlling the operation of a power switch. Considered below is the functioning of the circuit under different conditions.

In the condition illustrated in Fig. 140 the switch *S* in the circuit of the power transformer is open, which is evidenced by the burning indicating light *OL* in the tripping circuit. The indicating light is energized by the action of the pilot relay *OPR*. The current takes the path through the positive side of the control ties *CT*—fuse *1F*—the winding of the relay *OPR*—the auxiliary break contacts *AC*—the coil winding of the contactor *C*—fuse *2F*—the negative side of the control ties *CT*.

Since the current flows through the winding of the relay *OPR*, the make contacts (*10-11*) of the relay will be closed and the light *OL* energized. The current will take the path through the positive side of the signalling ties *SgT*—the closed contacts (*10-11*) of the relay *OPR*—the indicating light *OL* (*1-2*) the negative side of the signalling ties *SgT*.

Closing. The switch is closed by means of the control key *CK*.

Setting the key to the ON position will complete the circuit: *CT—1F—CK* (*13* and *15*)—the auxiliary break contacts *AC*—the winding of the contactor *C—2F*—the "—" side of *CT*.

The coil winding of the contactor *C* will be thus inserted between the positive and negative sides of the control ties *CT*, and the contactor will therefore operate to close its make contacts in the circuit of the closing electromagnet *CE* inserted between the positive and negative sides of the supply ties *ST*.

The electromagnet *CE* will operate to close the switch in the circuit of the power transformer, which will produce the following changes in the circuit. The auxiliary contacts *AC* connected in series with the coil of the contactor *C* will part, thus interrupting the current supply to the relay *OPR* and hence to the indicating light *OL*. The auxiliary make contacts *AC* in the circuit of the opening electromagnet *OE* will close, with the relay *CPR* and the associated indicating light *CL* energized as a result. The current through the relay

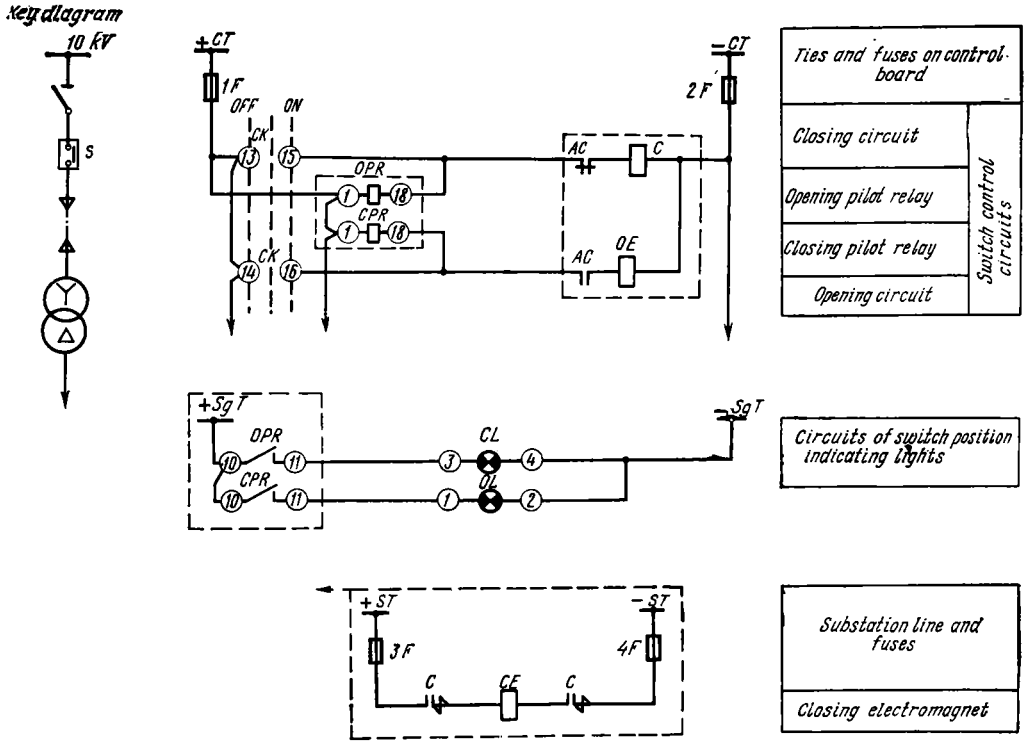


Fig. 140. Power switch control circuit. Breakdown schematic diagram

CPR will take the path through the positive side of *CT*— — *1F* — *CPR* (*1* and *18*)—the auxiliary contact *AC* closed on closure of the switch—the coil of *OE*—*2F*—the negative side of *CT*. The circuit of the light *CL* will be completed through the "—" side of *SgT*—*CPR* (*10-11*) — *CL* (*3-4*)— the "—" side of *SgT*.

Opening. The switch is opened by setting the same control key *CK* to the OFF position. The resulting circuit will be completed through the "+" side of *CT* — *1F* — *CK* (*14* and *16*)—the auxiliary make contact *AC* closed in the closed position of the switch—the opening electromagnet *OE* — *2F* — the "—" side of *CT*.

The switch will be opened by the action of the electromagnet *OE* connected into the circuit of the control ties *CT*, which will produce the following changes. As soon as the circuit of the electromagnet *OE* will be interrupted at the auxiliary contact *AC*, the relay *CPR* and hence the indicating light *CL* will be de-energized. The closure of the auxiliary contacts *AC* connected in series with the coil of the contactor *C* will cause the relay *OPR* to operate and the indicating light *OL* to go on.

14 Installation of Control Boards

The main switching points of control circuits are grouped on control boards. Control boards are delivered to the erection site as separate panels which are then mounted in place and integrated into a single set.

After the separate panels of a control board have been received at the site, they must first of all be checked by the installation crew for compliance with the working drawings as to their construction, the layout of the electrical equipment, the wiring connections, and the relative positions of the panels. The electrical equipment on each panel and on a control board as a whole must be such as specified in the circuit diagrams.

The apparatus and instruments dismantled for transportation and shipped separately packed should be thoroughly inspected for missing parts and possible damage.

The insulation of the panel wiring should be intact. The wires should be run to the terminals without undue tension

to avoid mechanical stresses at the contacts. The wires and their fixing straps should be laid on insulating pads, and identification tags should be provided on both ends of each wire at the respective device and at the terminal block assembly. Each identification tag should be legibly marked.

The insulation resistance of all the control wiring, within any one main-connection set should be at least 1 to 10 MΩ.

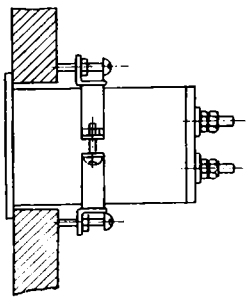


Fig. 141. Mounting and securing of instrument on control board panel

For this requirement to be complied with, the insulation resistance of specific cables and panels should be not less than 50 to 100 MΩ. The insulation resistance should be measured with a 500 to 1 000-V megohmmeter.

The surfaces of the panels should be smooth, free of dents, nicks, or buckles, and the cut-outs for the instruments should have smooth edges free from burrs.

A control board is assembled and installed according to the working drawings which must be studied in detail before any work is started.

The panels can be conveniently moved into the control room by a truck crane through an opening left in a wall by the builders for mounting purposes or, in the absence of such, through a window opening. Tackle blocks or winches can be used if a truck crane is not available. Inside the control room the control boards may be moved into place over channels with a winch and blocks. Another possible way is to move them on rollers.

Control board panels are mounted on a supporting frame set up in advance by the builders to the drawing furnished

by the contractor. It is good practice to mount the middle panel first. Once all the panels are in place, the position of the board on the supporting frame is checked with a plumb line and level. Then the panels are joined together and welded to the frame, at no less than four points each. The instru-

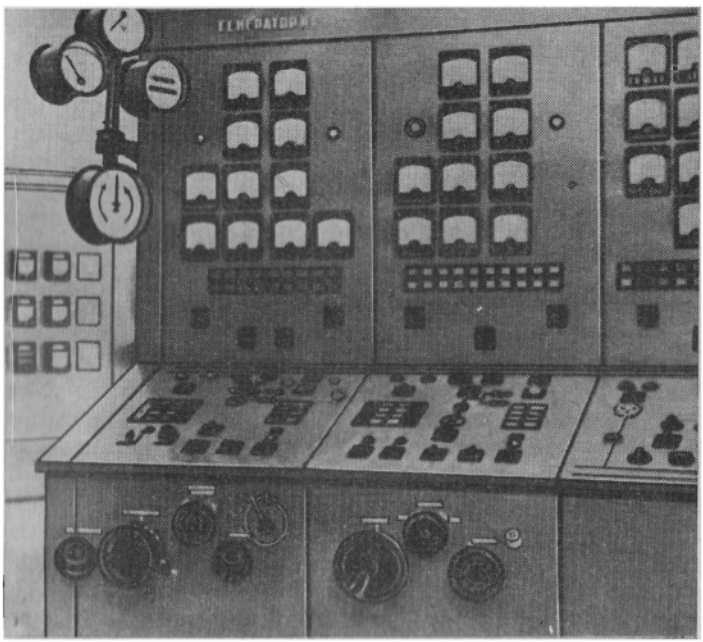


Fig. 142. Section of control board

ments and devices can now be mounted on the panels to the working drawings of the respective panels. The supporting frame must be connected to the main grounding mat at no less than two points.

The installation of some of the components of a control board is illustrated in Fig. 141. Fig. 142 is the general view of a section of the control board in a large electric power station.

35. Installation of Control Wiring

Panel wiring is generally done with ПР rubber-insulated copper-conductor wire or ПРЛ rubber-insulated copper-conductor varnished wire laid and secured on strips of electric-grade cardboard cemented to the panels with phenol-

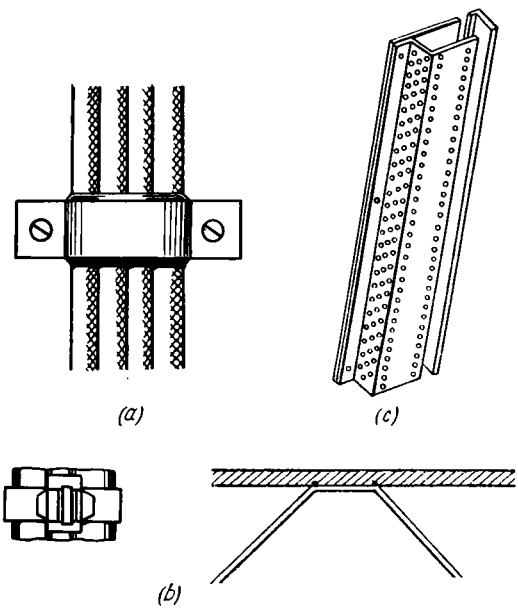


Fig. 143. Methods of panel wiring
(*a*) by straps secured to panel sheet; (*b*) by panel clips; (*c*) in perforated duct

formaldehyde lacquer. The wires are secured in place with sheet-steel straps fixed by screws (Fig. 143*a*) or with clips welded to the panel (Fig. 143*b*). The attachment points should be spaced 120 to 150 mm apart. Pads of electric-grade cardboard should be placed under the straps or clips.

Another method applied to control wiring is that of bunched or group wiring by which the wires are run without being directly secured to the panel surface. The wires leaving a terminal block in the same general direction are grouped

into bunches arranged in a convenient manner. Each bunch is formed to have a rectangular cross section and held together by metal straps spaced up to 200 mm apart. The straps are made of tin plate 0.3-0.4 mm thick, or of sheet aluminum up to 0.6 mm thick. To avoid damage to the insulation of the wires, liners of thin electric-grade cardboard are placed under the straps locked on the bunch by means of a fold-over joint.

The bunched wires are connected to the panel terminal block at one end and to the terminals of the respective devices at the other. When a bunch is run for over one metre, it should be secured to the panel by brackets at intermediate points.

Panel wiring can be greatly simplified and its cost reduced by the use of perforated ducts which make it possible to dispense with the labour-consuming operations necessitated by the conventional wiring methods. A perforated duct (Fig. 143*c*) has holes to receive insulating grommets safeguarding the wire insulation against damage. Fixed at the lower end of the duct is a terminal block from which the loosely bunched wires are passed up the ductway. The wires are brought out through the insulating grommets at the proper points for connection to the terminals of the respective devices.

Lines connecting the switchgear and the control board mainly employ control cables such as Grades КВРБГ, КАСРБГ, КАСБГ, etc., run on the surfaces of the structure, in floor ducts, basements, tunnels, or wells. In laying these cables, wide use is made of various metal supports fabricated in erecting shops, generally of 40 × 40 × 4 mm steel angles, 5 to 7 mm steel rounds, and 50 × 4 mm or 40 × 4 mm steel strips. The supports are grouted in at prelocated points. A method widely used today is to weld cable supports to metal inserts embedded in the surface of the structure during construction.

In outdoor substations the control circuits generally employ armoured control cable such as Grades КСРБ and КСБ laid in cable trenches. Where the cables are brought out to switchgear equipment they are enclosed in rigid steel conduits raised up to 1.5 m high for protection against mechanical injury.

36. Fanning-Out and Connection of Wires and Cables at Terminal Blocks

Fanning-out. All connections in control circuits are made at terminal blocks (Fig. 144) secured on steel supports made of plain strips, perforated strips, or suitable shapes. A block must have as many terminals as there are circuits in a given

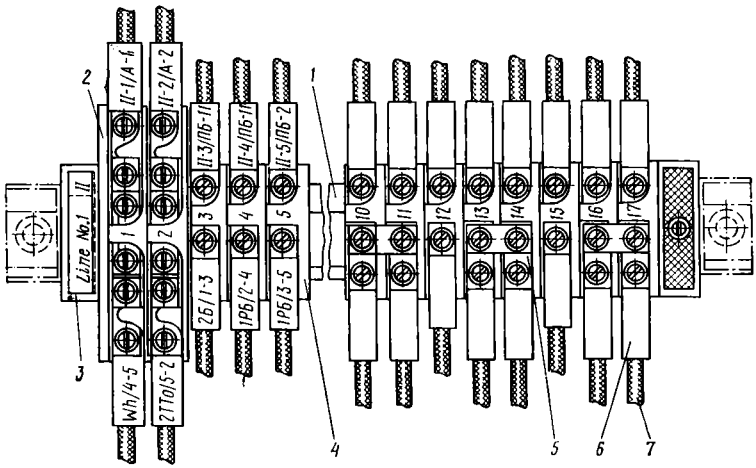


Fig. 144. Several terminal blocks with connected wires

1—binding plate; *2*—KH test terminal; *3*—identification tally; *4*—KH regular-type terminal; *5*—KC special-type terminal; *6*—identification tags; *7*—wires

system, which is determined from the wiring diagram prior to installation. A row of terminals should be placed 70 to 150 mm away from the centre line of the last fixing strap of the incoming wires.

Before the panel wires may be connected to a terminal block, their ends should be straightened by running a paraffin-soaked rag down the wire. To avoid damage to the insulation under the straps, one should not pull the wires away. It is good practice to back off one of the screws on the lower strap when straightening a wire. Once straightened, the wires are laid back under the strap and the screws are tightened.

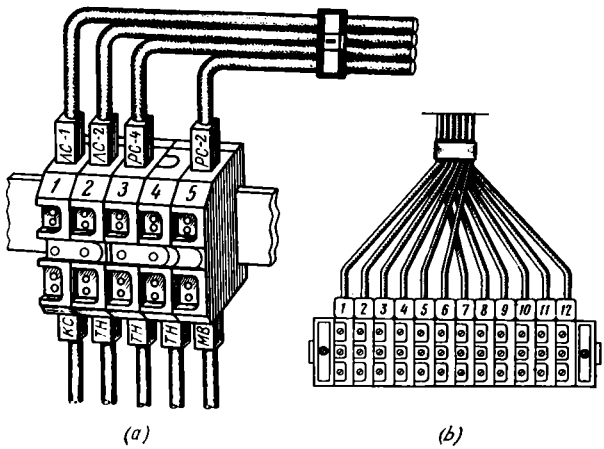


Fig. 145. Fanning-out of wires and control cables
(*a*) single-layer arrangement; (*b*) multilayer arrangement

Fanning-out, or the arrangement of the wires and control cables, should be started at the extreme terminals. First one of the outer wires, and then the other, are measured off, bent, stripped, and inserted under the respective terminal. The two wires are straightened out in a horizontal plane, and the same procedure is followed with the two wires adjacent to the first ones, and so on, gradually progressing towards the centre. The extreme wires serve, so to speak, as templates for the other wires (Fig. 145*a*). For a wire or cable conductor to be kept in place in the course of work, it should be temporarily secured with a piece of taffeta or herringbone tape.

Where there are more than 50 wires, they have to be arranged in several rather than in one layer (Fig. 145*b*).

Connection to terminal blocks. The copper conductors of wires and cables are connected to terminal blocks and equipment terminals by the universally known methods discussed in the courses of general training for electric installation work. The ends of the single-wire conductors to be connected

are shaped into "pins" or "rings". Multiwire conductors are first terminated in suitable lugs soldered or crimped to place.

At present, however, most wires and cables have aluminium conductors. Some recommended practices of terminating and connecting aluminium conductors to terminals are set forth in installation directions.

To connect aluminium conductors to flat-face terminals, use is made of lock and C-type washers (Fig. 146*a*).

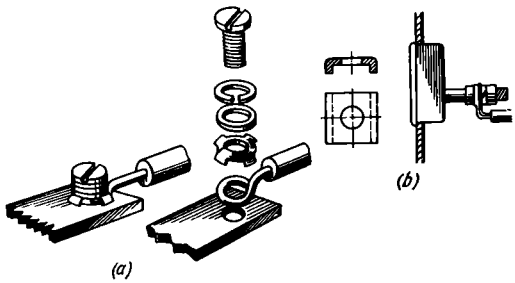


Fig. 146. Connection of aluminium cable conductors to equipment terminals

(*a*) with washers; (*b*) with crimp-on lug

The conductors to be connected to terminal clamps had better be prefitted with crimp-on lugs (Fig. 146*b*) secured in place by means of a special-purpose swaging tool.

A presently used technique is to employ adapter rods made up of aluminium and copper conductors butt-jointed by compression. The aluminium portion of such a rod is crimped to the aluminium conductor of the line being installed, and the copper portion is inserted into the terminal.

Termination of control cables. With control cables, rather than wires, brought to a terminal, their ends must be sealed in advance. Before this the cable is terminated by removing its separate sheaths in succession.

The termination of a rubber-insulated cable is illustrated in Fig. 147. The rubber insulation of each conductor is coated with Grade ИКФ varnish and dusted with talc. The "root" of the terminated end is tied with a length of twisted cord and coated with the same varnish and talc.

The termination of a paper-insulated cable in a steel or plastic pothead is shown in Fig. 148. First the pothead is slipped on the cable and pushed down out of the way. Next the successive termination of the cable is performed. In contrast to the regular pattern of power cable termination,

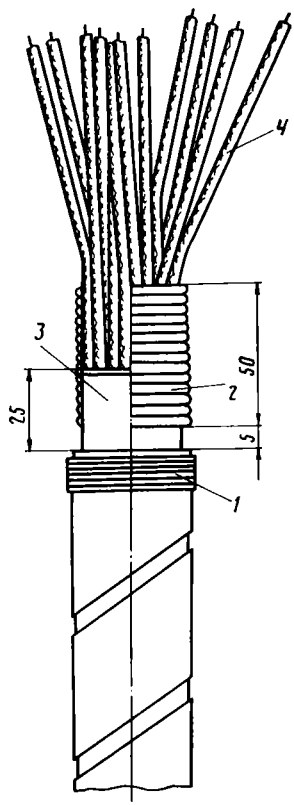


Fig. 147. "Dry" termination of rubber-insulated control cable

1—serving of binding wire or armouring tape; 2—serving of twisted cord; 3—air-tight sheath; 4—cable conductor

the cable is stripped of its core insulation as well for 20 to 25 mm from the "root" downwards. Each of the bared conductors is then thoroughly degreased with acetone or petrol and given a coat of Grade IIXB-26 perchlorvinyl enamel. Following this, a length of PVC tubing cut askew at the lower end is slipped over each conductor so that it positively overlaps the remaining insulation.

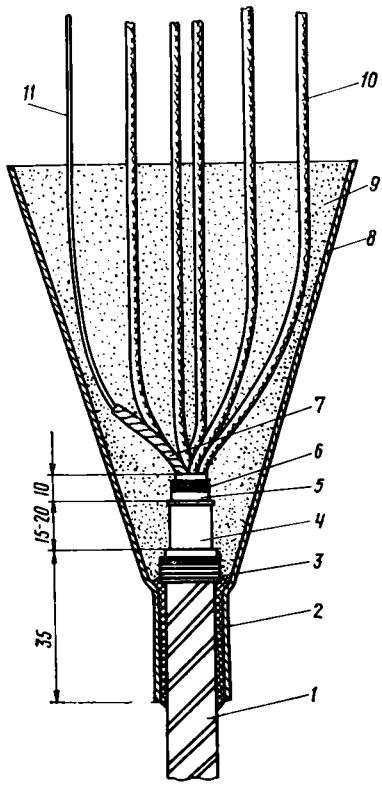


Fig. 148. Termination of paper-insulated control cable in steel or plastic pothead

1—tape armouring; *2*—sealing of tarred tape; *3*—wire serving over wrapping of tarred tape; *4*—air-tight cable sheath; *5*—paper belt insulation; *6*—serving of three or four wraps of thin twisted cord or coarse thread; *7*—cable-core insulation; *8*—pothead body; *9*—cable compound; *10*—PVC tubing on bared cable conductor; *11*—bared cable conductor

Before the pothead is moved in place, tarred tape is wound in several layers over the cable for about the length of the pothead throat. Once in place, the pothead is filled with cable compound such as Grade MBM-1 or MBM-2 (bituminous, frost-resistant). Grade MK-45 (rosin-bearing) is also acceptable. The heat-up temperature is 170 to 180°C for the first two grades and 140°C for the third one.

The filling is accomplished in two or three steps. First the pothead should be two-thirds full of compound. After the last portion of compound has been filled in, a cover put on the cable conductors is pushed down into intimate contact with the compound before it solidifies.

A method practised in installation work is to wrap a piece of PVC tubing cut lengthwise around the "root", heat

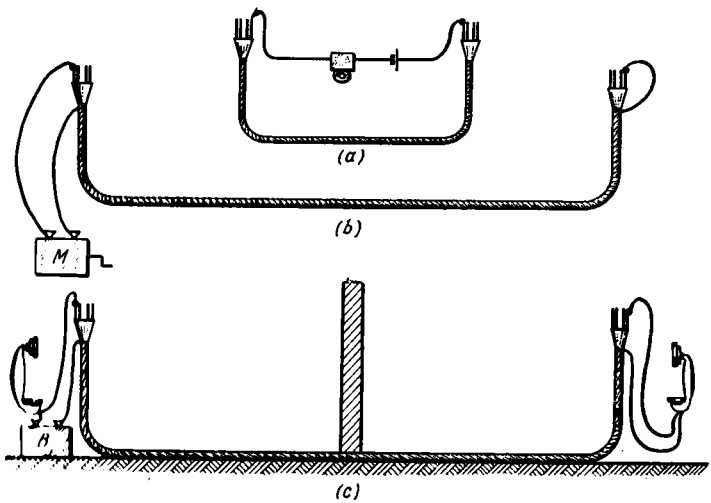


Fig. 149. Control cable identification setups using (*a*) bell; (*b*) megohmmeter; (*c*) handsets

up the outer end of the tubing and press it against the wrapping for bonding. A length of protective PVC tubing is slipped over each cable conductor in the same manner as described above.

Identification of cable conductors and wires. To connect all the components of a specific control circuit according to the design, the ends of the wires and cables have to be prearranged in a particular manner. The purpose of this operation is to pick the current conductors one by one at one end of a section and identify them in succession at the other end.

In the simplest case use is made of the circuit arrangement shown in Fig. 149*a* where a bell is employed as an

aural indicator. On long sections use is generally made of the circuit arrangement shown in Fig. 149*b* where the bell and dry cell are substituted by a megohmmeter (*M*). The circuit arrangement depicted in Fig. 149*c* is convenient for indoor use. The workers performing the operation can use handsets to speak to each other.

In the above circuit arrangements the air-tight metal sheath of the cable serves as the return conductor. If the line under test is run with a plastic-sheathed cable or unprotected wire, the switchgear earthing connection or one of the earlier identified wires is used as the return conductor.

37. Mounting of Storage Batteries *

Direct current operative supply for the control circuits is provided by storage batteries. Storage-battery rooms (Fig. 150) are amply ventilated to remove the gases and sulphuric acid fumes evolved by the batteries.

Preparatory operations. Storage batteries are mounted on wooden racks *1* which must be primed and given two coats of hot drying oil followed by a coat of acid-resistant paint. It is advisable to paint the racks with (light-gray) acid-resistant enamel No. 1, Grade ДП enamel, etc. The racks should not be longer than 6 m each. Bar joints are located so as to rest on pedestals. The positions of the racks are laid out to the drawing, taking into account that the aisles between the racks must be at least 1 m wide and the battery cell jars must be placed 150 mm from the walls as a minimum. Once installed, racks should be thoroughly levelled.

Racks are set up directly on the floor of the storage-battery room, provided it is covered with concrete or paved with ceramic tiles. Where rack pedestals are to be installed on an asphalt-covered floor, the asphalt is cut out to be substituted by ceramic tiles.

Mounting of battery cell jars. Glass cell jars are unpacked and inspected for cracks. Damaged jars are rejected and those found fit for installation are washed with distilled water and wiped dry. At the same time the glass support

* Lead batteries are discussed as the most common type.

insulators, on which the jars are to be mounted, are checked to ensure that they are intact.

Prior to mounting the jars, the support insulators should be set up, preferably using a template of 6 to 8 mm thick plywood shaped after the jar base and provided with holes

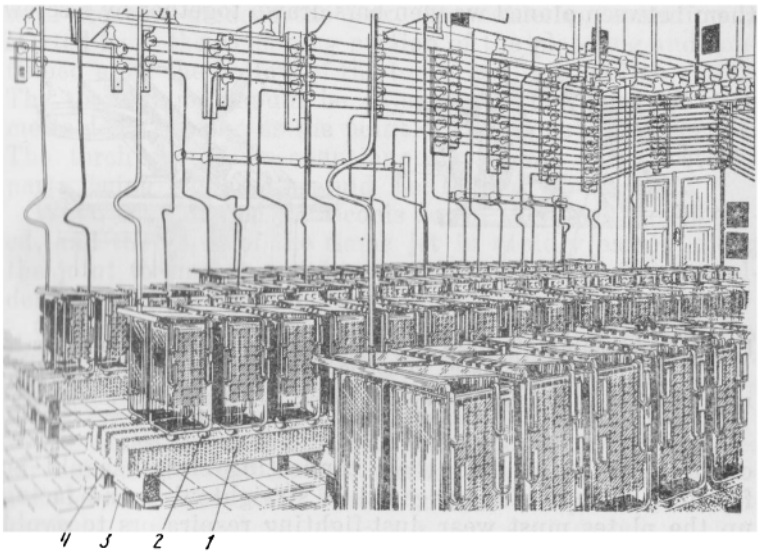


Fig. 150. Storage-battery room
1 rack; *2*—glass insulator; *3*—pedestal; *4*—glass pad

at the intended insulator locations. The jars are placed on washers of lead or acid-resistant plastic put on the tops of the insulators, whereupon the jars are levelled with a straight edge and spirit level. Misalignment, if any, can be remedied by placing additional washers under the jars. The jars should be lined up against a cord. They should be firm and steady in their places, which is checked by pressing each jar downwards.

Mounting of plates. Once the jars are in place, they are followed by the plates which should be first inspected for possible defects. One should remember that positive plates must have a uniform active layer without sulphated, crumbl-

ing areas on the surface. Negative plates must not have holes exceeding 2 mm in diameter. The plates must be free of cracks, cavities, etc. While under inspection, the plates are classified under two types, positive and negative (central and peripheral).

Bent plates, if any, should be straightened by clamping them between planed wooden bars drawn together by a screw

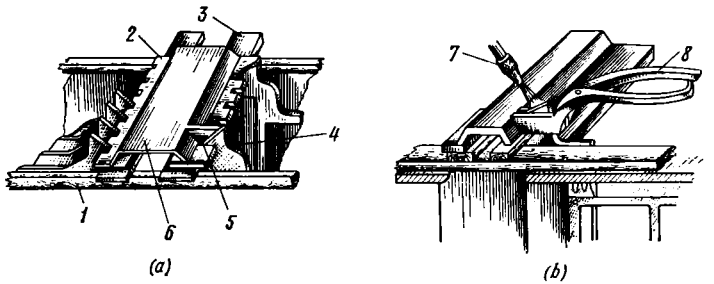


Fig. 151. Assembly of plates to template (*a*); application of tongs to solder plates to connecting strip (*b*)

1—wooden bar; *2*—template; *3*—wooden straps; *4*—battery plate lug; *5*—connecting plate lug; *6*—connecting strip; *7*—propane torch; *8*—tongs

clamp. The plates and their connecting strips should be faced up. The workers engaged in straightening and facing up the plates must wear dust-fighting respirators to avoid injury by lead deposits.

In placing the plates into the jars, use is made of templates in the form of a metal rule with cut-outs.

To assemble the installed plates, placed on the edges of adjacent jars are wooden bars *1* (Fig. 151*a*) and straps *3* arranged at right angles to the bars. Template *2* is laid over the straps, and connecting strip *6*, on top of the template. In selecting the bars and straps, care should be taken to ensure that the extending portion of plate lug *4* sticks up 5-6 mm above the connecting strip. The plate lugs should fit tightly in the template cut-outs. The space between the lugs of the adjacent plates must be equally divided in half by the connecting strip.

The plates are installed in the following order: the outer, negative plate is followed first by all positive plates and then by all negative plates.

The plates are joined to the connecting plates by soldering in the flame of acetylene or propane torch 7 (Fig. 151*b*). The areas to be soldered are scraped with a steel-wire brush and clamped together with a pair of tongs 8. The worker doing the scraping must wear a dust-fighting respirator. The filler metal employed is lead cut in strips 10 to 12 mm wide, with stearine used as the flux. The soldering operation is started from the extending portion of the plate lug and continued until the hollow of the tongs is full of molten metal. The torch flame should be adjusted so that the lead strip melts down as soon as the point of the flame jet touches it. The torch should be countinuously moved along lest the parts being soldered should be burned.

When the soldered joint cools down, the tongs are removed, and the point of the flame jet is rapidly passed along the joint to smooth wrinkles and rolls. The quality of soldering is checked by shaking a little the joined plates.

Once the plates are soldered, each jar should be thoroughly inspected for remaining pieces of lead which must be removed. All the cells must also be checked for shorts using a discharge tester or high-resistance voltmeter.

The necessary clearance between the outer plates and the jar walls is provided by lead springs at one end, and by rubber sleeves at the other. Placed between the plates are separators.

Preparation of electrolyte. The electrolyte is prepared in a wooden vat lined with lead on the inside. Distilled water must first be poured into the vat and followed (never in opposite order!) by a thin jet of battery sulphuric acid issued from a small bottle or beaker of a maximum 1-2 l capacity. While adding the acid, the solution should be stirred with a glass rod.

While being prepared, the electrolyte appreciably heats up and should therefore be allowed to cool to a temperature anywhere between 25 and 30°C. The density of the electrolyte must be subsequently adjusted to 1.18 g/cm^3 as measured with an acidometer. Some of the ready electrolyte is poured out, by means of a rubber bulb, into a clean glass flask having a ground glass stopper and subjected to a laboratory analysis.

Filling the storage-cell jars with electrolyte. Preparatory

to filling, each jar should be blown out with compressed air using a pair of hand-operated bellows. Electrolyte is brought to the site in glass bottles put in wicker baskets with two handles each or in latticed wooden boxes. To fill the electrolyte into the jars, use is made of a siphon provided with a clamp (Fig. 152) to check, if required, the flow of electrolyte. The electrolyte level in the storage-cell jars

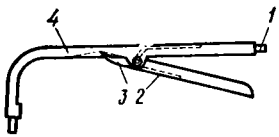


Fig. 152. Clamp used in pouring electrolyte
1—rubber pipe; *2*—spring; *3*—point where pipe is pinched; *4*—metal body

must be 10 to 15 mm above the upper edges of the plates. The level is checked with a glass tube 5-6 mm in diameter and 150 to 200 mm long. The tube is set on the upper edge of a plate and closed at the end. The height of the column of electrolyte in the tube taken out of the jar will be that of the electrolyte surface above the plate edges.

On filling the electrolyte into all the jars, each of them should be checked for electrolyte density. Then a sheet of window glass is put on top of each jar. The size of the glass sheet must be 5 to 7 mm less than the inner dimension of the jar in order to let the condensate drain off into the jar.

While handling the acid and electrolyte in the storage-battery room, the personnel must wear rubber boots, aprons, and gloves, woolen overalls, and protective goggles. Always near at hand must be a 5 per cent solution of sodium bicarbonate to wash the skin areas injured by acid or electrolyte.

The storage battery to be formed and charged is connected to a battery charger, observing the polarity of the terminals (Fig. 153). The battery charger is then turned on, and the required charge rate adjusted by a timing rheostat inserted into the battery circuit. The charge rate must be selected from the tables recommended by the manufacturer's instructions.

Storage batteries must be formed and charged in compliance with the manufacturer's instructions.

Installation of storage battery buses. The bus system is assembled of round copper bars generally carried by support insulators and, though less often, by ПСШ pin-type insulators (the letter Ш stands for "pin-type", С, for "moist

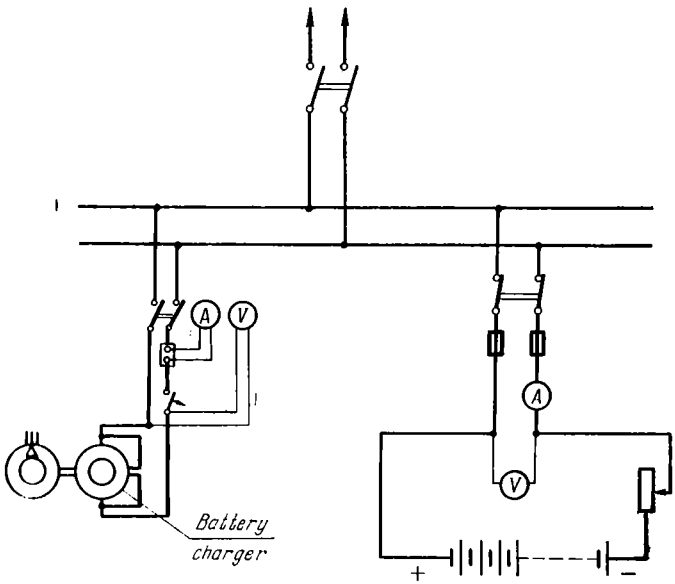


Fig. 153. Connection of storage battery to battery charger

atmospheres"). The insulators are mounted on supports built from steel angles grouted in the walls of the battery room, or secured by dowels driven with an СМП gun. Busbars are secured to the insulators with copper straps or clamps. Lead liners are installed at the attachment points.

Busbars are joined by soldering in the flame of gas (propane) torches, with connecting sleeves placed on the joints. The lead bars of battery cells are soldered into the lugs on the lead battery plates.

The busbars from the battery room are brought out to the DC board by means of an asbestos cement slab. The slab has

through bolts fitted with two washers on either side. The washer placed directly against the slab surface is of lead, and the other of steel.

Questions

1. What is the purpose of switchgear control circuits?
2. What types of circuit arrangement are used in control circuits?
3. Use a given circuit diagram to analyze the interaction between the specific components of the control circuit.
4. What is the basic approach to control board installation?
5. What main techniques of panel wiring do you know?
6. What methods are available for fanning out wires and cables and connecting them to terminal blocks?
7. What methods of control cable termination are applied to secondary circuits?
8. Describe the basic design and operating principle of storage batteries providing DC operative supply for control circuits.

CHAPTER 7

Accident Prevention in Switchgear Installation

38. General

Before any erection work may be started, all personnel must be briefed on general rules of accident prevention by the persons responsible for safety. In addition, every worker must observe all safety regulations specific to his job set forth in statutory publications and in safety booklets.

Caution signs and warning boards must be posted at all places where danger may exist. All wall and floor openings must be fenced off, and ample daylight illumination or artificial lighting must be provided throughout the premises.

Electric-driven machine tools or mechanisms should be checked for reliable earthing before use. The frames of electric hand tools must have earthing devices.

Portable lamps rated for at most 36 V should be normally used, and for work in damp and moist locations, in circuit-breaker tanks, and on metal structures, lamps rated for at most 12 V must be used.

Temporary electric circuits must comply with the applicable requirements of the electric installation code. Use should be preferably made of take-down equipment for temporary electric power supply.

First-aid kits should be provided on the site. All personnel must know how to break an electric shock victim's contact with the source of current and to render him first aid, how to put out fires in electrical plant and how to use fire fighting equipment.

39. Safety Rules for Use of Hand Tools

Wooden tool handles must be made of hardwood (such as beech, oak, maple, etc.), and the tools proper (hammers, sledges) securely and properly seated on their handles. The

striking faces of hammers and similar tools must have no ragged edges. Cold chisels must be at least 150 mm long, pitching chisels and jumpers, not less than 200 mm long. Spanners must precisely fit the size of nuts.

Electric tools operating on 127 and 220 V may be used provided their frames are reliably earthed and the operator wears nonconducting gloves. At present electric tools with insulated frames are introduced for everyday use. It is prohibited to operate an electric tool while standing on a step ladder or stairs. When necessary, scaffolding and falsework should be used.

Pneumatic tools and powder-actuated dowel guns of the CMII type may only be used by specially trained personnel.

40. General Safety Rules for Hoisting

Before hoisting any piece of equipment, all hoisting facilities must be checked for possible defects. Ropes and cables must have no breaks and be of appropriate size for the loads to be handled. The splices of loops at rope ends should be at least 25 rope diameters long, or the loop should be made with at least three bolt clamps.

Wire ropes should be free of kinks. Ropes or cables to be used with tackle blocks or hoists should never be spliced or have any defects.

Slings may be attached to a load only where it is allowed to. When long pieces of equipment are to be lifted, at least two slings and a spreader should be used.

Electrical equipment must be hoisted only by the lifting lugs and rings (eyes) provided for the purpose. When the equipment to be lifted has sharp edges, special wooden or metal pads should be placed under the slings so that they will not drop out when the load is being lifted or lowered.

Nobody should be allowed to stand under a load being lifted. While lifting a load, it is prohibited to adjust the lifting hitch or touch the lifting ropes or cables. The lifting hook may only be disengaged after the load is fully lowered, reliably seated, and secured. Hoisting personnel must be well versed in the conventional signals and commands.

41. Safety Rules for Installation of Main Electrical Equipment

Where equipment has to be set up at a height over 1.5 m, use should be made of scaffolding and falsework provided with rails 1 m high and floor toe boards to prevent tools from falling. Pieces of equipment up to 20 kg in weight should be lifted in place and mounted by two workers. Heavier apparatus should be handled with blocks and hoists when installing it indoors, and with portable booms and truck cranes in outdoor substations.

Prior to installation of equipment, the supporting structures and fasteners should be checked for security and strength.

Isolator blades and the tie rods between an isolator and its operating mechanism should be adjusted by an electrician and his mate working in concord in order to avoid injury to their arms by the moving parts of the apparatus. Special care must be exercised when the blades of BH-16 load-breaking isolators are being adjusted. Lack of attention or failure to work in concord may result in serious injury to the man adjusting the movable arcing contacts.

Power switches may be moved only when they are in the closed position.

An electrician adjusting tie rods and contacts must work in close agreement with his mate handling the associated operating mechanism.

Before closing or opening a breaker by remote control, the manual control lever should be removed.

It is not allowed to be inside a circuit-breaker tank, stick one's head into it, or touch any moving parts of a circuit breaker being operated.

Questions

1. What general rules of accident prevention should be observed in the course of electric installation work?
2. What safety requirements are imposed on hand tools?
3. What safety requirements are imposed on electric hand tools?
4. What safety rules should be observed by those working at a height?
5. What are the main safety requirements for hoisting operations?
6. What safety requirements should be complied with while main switchgear equipment is installed?

CHAPTER 8

Erection of Overhead Power Lines

42. Elements of Overhead Lines and Erection Procedure

The main elements of an overhead line are the line supports and their foundations, insulators, line accessories, conductors, and earth wires.

By function, line supports are classed into tangent-suspension supports which carry the conductors, and anchor supports which take up the entire tension due to all the conductors and earth wires. Supports at the ends of a line are called terminal supports, and supports placed where angle turns occur in a line are termed angle-suspension supports. Terminal supports take up the one-sided tension due to the conductors and earth wires.

The foundations of wood-pole supports may be reinforced-concrete or wood-pole stubs buried in the soil, or driven in like piles. For reinforced-concrete and metal supports, the foundations may be reinforced-concrete piles, prefabricated reinforced-concrete members, or cast-in-place concrete or reinforced-concrete foundations.

Power lines employ aluminium and steel-cored aluminium conductors carried by strings of suspension insulators.

Line erection includes:

preparation for line construction which covers locating and laying out the line, clearing work, and erection of the necessary structures and services;

line construction which covers delivery of line supports, conductors, and insulators to their sites, their assembly and erection.

43. Erection of Supports

Wood-pole support erection. Wood-pole supports are most commonly erected by the so-called falling derrick pole method. The derrick pole may be made of wood or metal. Wood

poles are used more often because they have a relatively small weight, are cheaper to make and easier to transport.

Derrick poles 10 m and over long are fabricated from metal, as wood poles would have to be made from several logs joined together, which is an obvious inconvenience.

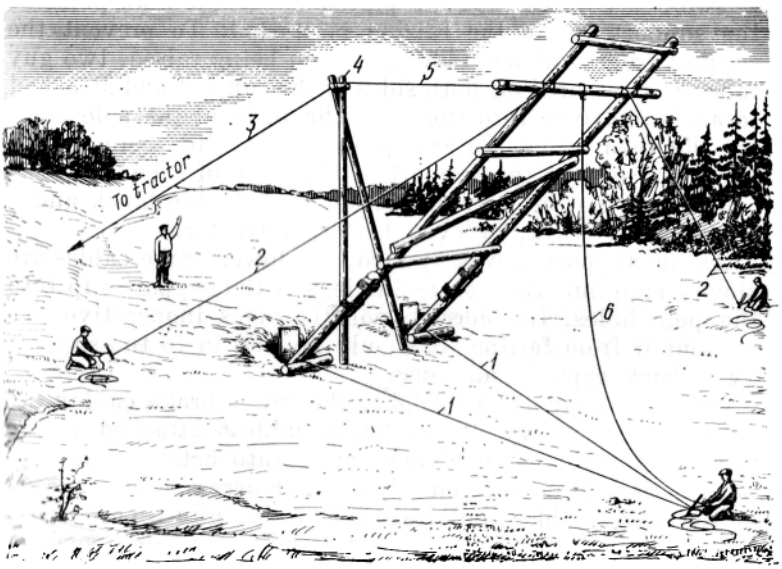


Fig. 154. Erection of H-frame wood-pole support with falling derrick pole

Considered below is the erection of an H-frame wood-pole support with a falling derrick pole of wood (Fig. 154). The support is arranged along the line route so that its stub-pole footings are just above the holes dug out in the soil. Derrick pole *4* is placed so that its legs are within 1 to 1.5 m of the holes and between the stub poles. Two side pull ropes *5* connecting the derrick pole with the support and raising line *3* run to a tractor or winch are attached to the top of the derrick pole. Two more ropes *1* are made fast to the stubs to prevent the support from being dragged in the di-

rection of the pull at the instant the raising is started. These ropes are referred to as lower brake cables.

The derrick pole is raised into position by means of so-called shoring poles consisting of two round baulks 3.5 to 4 m long each and resembling a derrick pole of smaller size.

Two short round logs are placed under the stub poles of the support before the raising is started. To prevent the support from shifting sideways, when being raised, two guy ropes *2* are secured on both sides of the support and attached to anchors driven into the soil. The walls of the pole holes are sheathed by boards as a protection against being caved in by the legs of the support at the time of raising.

The pull can be provided either by a tackle block and a winch, or a truck, or even better, a tractor.

As the support moves upward, the lower brake cables are slowly paid out. As soon as the legs of the support slip into the pole holes, the derrick pole becomes inoperative. To prevent it from falling, it should be tied in to the support by a back rope in advance.

Once the support is upright, the lower brake cables are no longer necessary. Upper brake cable *6* attached to the middle of the cross-arm now comes into action. The support is then plumbed and adjusted, if necessary, by means of the brake cables, pull ropes, and side guy ropes. If the support is out of the vertical, it should be straightened by removing the soil from under its higher leg, or conversely, by slipping short boards under the lower leg, raising the legs with a jack.

When the support is aligned and adjusted, the pole holes are backfilled by ramming in one layer of earth upon another, whereupon the whole hoisting tackle is dismantled.

Erection of reinforced-concrete and metal supports. Reinforced-concrete poles are best erected with the use of a derrick pole and a tractor as the means of pull.

The derrick pole is secured to the upper and lower cross-arms of the support pole with ropes and placed above the support within 1.5 to 2 m of the pole butt. Where the ropes are tied to the support, the concrete should be protected by pads of hardwood. Brake cables are unnecessary in this case because the butt of the support, as it slips into the

pole hole, is immediately brought up against the wall of the hole.

The support pole is set upright by means of the pull rope and guy ropes.

Fig. 155. Erection of reinforced-concrete support

Reinforced-concrete supports may also be erected using a truck crane (Fig. 155), for which purpose a support is first lifted by a crane, and then lowered into the pole hole in the vertical position. The support is plumbed and aligned,

the hole backfilled, and the soil rammed in the same way as described above.

Metal supports are usually mounted on prefabricated reinforced-concrete foundations or on reinforced-concrete piles driven into the soil. For the heaviest supports, use is also made of cast-in-place concrete or reinforced-concrete foundations.

44. Safety Rules for Support Erection

Good hoisting facilities go a long way toward complete safety in support erection. The winches, blocks, tackle blocks, etc., should be registered in log books where their annual inspections and tests are recorded. The date of the last test should be marked with indelible paint or stamped with a die.

Before any work is commenced, all the tackle, irrespective of the date of the last test, must be inspected for cracks on the hooks and worn shaft pins of pulley blocks, and for damaged strands in the ropes and cables.

Under no circumstances may defective tackle be used.

Prior to pole erection, the brake cables and guy ropes should be checked for reliable fastening, as should be the pull ropes and raising lines for attachment to the support and to the truck crane or tractor.

Special attention should be paid to the condition and setting-up of derrick poles. For a more uniform distribution of pressure on the soil, timbers or boards should be placed under the legs of the derrick poles.

While a support is being raised, no one of the erection gang should be under the support, under the tight ropes, in a pole hole, or where the support or derrick pole may fall. Every man in the gang should be at his work station and within the sight of the foreman.

As soon as a support is set up, it must be guyed, and a watchman should be left at supports which are temporarily guyed.

A support may be climbed only after it has been fully anchored. When work is done on the support, nobody should be allowed to stand under it, as dangerous accidents may result from the fall of a tool, tackle parts, etc.

45. Installation of Conductors and Earth Wires

Reeling-out operations. Conductors and earth wires can be brought to the erection site on trucks, horse-drawn carts, or tractor-drawn trailers. In loading, transit, and unloading, cable drums should be protected from damage. Hence, cable drums must be securely fixed in the body of the vehicle be wedges and ropes. Cable drums should never be dropped and may be rolled only as indicated by the arrow on the drum side. The drums should be arranged along the route at intervals approximately equal to the length of the conductor or wire wound on the drum.

Insulators to install the conductors are brought to the site packed in boxes, or sometimes, unpacked and bedded in straw or hay. As many insulators as is required for installation are placed at each support, with allowance made for possible breakage.

The line accessories packed in cases are stored in the watchbox on the line and handed out when required.

Advanced reeling-out techniques enable the conductors and wires to be reeled out at the same time as insulator strings are lifted onto the supports. The procedure is as follows. Two auxiliary blocks are secured to the top and bottom of the first tangent-suspension support, and a hoisting rope is passed over the blocks (Fig. 156*a*). Attached to the end of the rope passed over the upper block are insulator strings with snatch blocks (Fig. 157) threaded on the conductors and the earth wire. The end of the hoisting rope passed over the lower block is fastened to the draw-bar hook of a payoff truck (see Fig. 156*b*) carrying the drums.

With the payoff truck towed by an automobile or tractor along the route, the hoisting rope will lift the insulator strings, conductors, and earth wire onto the support. After the insulator strings with the conductors and the earth wire have been secured on one support, the lifting tackle is transferred to the next support, and so on. Before the conductors and earth wire are reeled out, they should be secured to the anchor support from which they are run.

Where it is impossible to follow the above method, conductors and earth wires can be reeled out in a different manner. One possible way is to place the drum on a fixed pay-

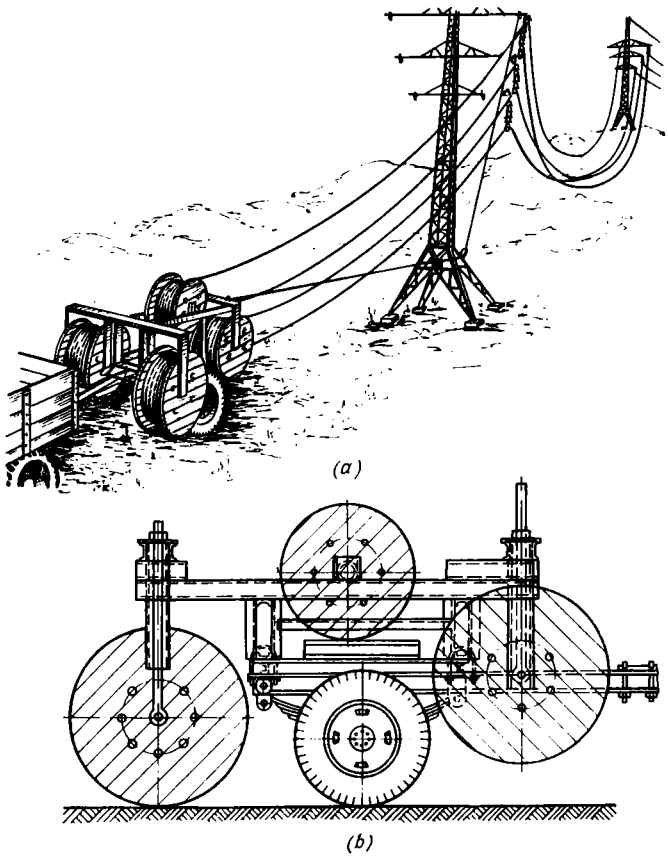


Fig. 156. Simultaneous reeling-out of three conductors and earth wire from four-drum payoff truck
(*a*) raising setup; (*b*) payoff truck

off stand and to reel out the conductors and earth wire by pulling them over the ground.

It should be noted that conductors and wires may be damaged while pulled over the ground, and hence should be thoroughly inspected once reeled out. Damaged sections should be repaired or cut out.

Conductor jointing. Conductor joints must be at least 90 per cent as strong as an intact conductor. The electrical resistance of a joint should not exceed that of an equal length of the conductor, and the temperature rise of the joint sleeve mounted on a conductor should not exceed that of

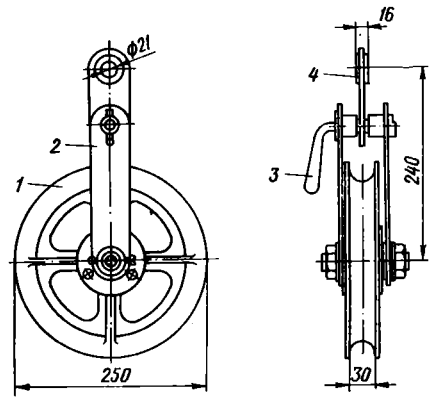


Fig. 157. Snatch block

1—sheave; *2*—cheek; *3*—locking handle; *4*—suspension link

the conductor proper when the maximum current permissible for the given conductor flows through the joint.

The three methods mainly used for jointing conductors are crimping, compression, and thermit welding. Crimp joints are used on copper, aluminium, and steel-cored aluminium conductors up to 240 mm² in size, compression joints on Grade ACV extra-strength steel-cored aluminium and Grade AC general-purpose steel-cored aluminium conductors of 300 and 400 mm² in size. Compression joints are also used on hollow copper conductors and steel earth wire of 50 mm² and greater size.

Joints produced by thermit welding feature good electric contact and relatively low mechanical strength. Because of this, thermit welding is used in combination with either of the two first methods.

Crimp joints. Joints of this type are made in a portable screw press; its design is shown in Fig. 158. The press con-

sists of two lever arms *1* and *6* hinged by pivot *2*, and stirrup *7* hinged to fixed lever arm *1* by pin *11*. The stirrup has threaded hole *9* into which bolt *8* is driven by two-arm handle *5* during crimping. The press is furnished with steel dies *3* secured in die seats *4* with screws. A set of dies consists of an upper and a lower die. Screw *10* is used to adjust the crimping force.

Each pair of dies is stamped with numerals corresponding to the conductor size for which the pair is to be used; both dies in a pair have identical ordinal numbers stamped on.

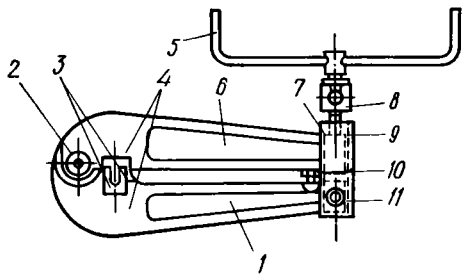


Fig. 158. Screw press for jointing conductors by crimping

After use, the dies must be removed, washed in petrol or kerosene, coated with petroleum jelly, and wrapped in heavy paper. The press should be lubricated with machine oil. Both the press and dies should be stored in a dry place.

Before jointing, the conductors should be first checked to see that they are arranged on the ground the same way as they should be strung on the supports. Servings of soft binding wire are applied to prevent the conductor strands from loosening, and the ends to be joined are cut square with a hacksaw or in the same press (see Fig. 158) fitted for the purpose with a pair of cutting dies.

The ends of the conductors are then cleaned for a length of 1.3 to 1.5 times their length to be sealed in the joint sleeve. With a heavily oxidized conductor, each strand is unravelled and cleaned separately. The conductor to be cleaned is first wiped with a dry rag, then with a rag soaked in

petrol, and finally wiped dry. The ends to be joined are given a thick coat of petroleum jelly or protective paste and cleaned with a steel-wire brush. The same treatment is given to the inside of the joint sleeve, with the difference that a steel-wire tube brush is used.

The protective paste consists of petroleum jelly to protect the contact surface from oxidation and zinc powder which, being harder than aluminium, becomes embedded in the conductor material and provides contact bridges within the joint over its entire length. A protective paste is now available in which the zinc powder is substituted by quartz sand.

Before crimping the conductors together, dies *3* and the oval joint sleeve are checked to see whether they fit the diameter of the conductors. The dies are then set in place so that the letters and numerals stamped on them are on the same side. The clearance between the dies is adjusted, by means of stop screw *10*, to 0.4-0.5 mm as checked with a feeler gauge. Next the conductors are pushed into the sleeve from the opposite ends, until they extend outward about 15 to 20 mm. The scribe marks on the edges of the sleeve should be on the side of the outgoing conductors.

The joint sleeve, with the conductors pushed into it, is placed between the dies and crimped by turning two-arm handle *5*. Each time lever arm *6* is brought in contact with the stop screw, the joint should be held clamped between the dies for 1 to 1.5 min. The crimps on the ready joint are checked for proper depth against Table 16.

The joint is crimped beginning at one end and proceeding towards the other end in a staggered sequence as indicated by the scribe marks on the sleeve (Fig. 159*a*).

It must be remembered that the number of scribe marks on the joint sleeve varies with the size of the conductor (Table 17).

On steel-cored aluminium conductors, the joint is crimped beginning at the centre of the joint sleeve and proceeding towards its ends.

Grade AC steel-cored aluminium conductors of 240 mm^2 size or greater are jointed using two sleeves (Fig. 159*b*).

Compression joints. Joints of this type are made in a hydraulic press unit (Fig. 160) made up of hydraulic press *1* with a piston 120 mm in diameter in which the lower die is

Table 16

Depth of Crimping on Oval Joint Sleeves for Aluminium and Steel-Cored Aluminium Conductors

Conductor size, mm²	Depth, mm						Sketch
	Grade A aluminium wire			Grade AC steel-cored aluminium wire			
	a	*b*	*c*	*a*	*b*	*c*	
16	15.4	10.5	4.9	—	—	—	
25	15.4	12.5	5.3	—	—	—	
35	20.4	14.0	6.4	23.2	17.5	5.7	
50	23.4	16.5	6.9	26.6	20.5	6.1	
70	26.6	19.5	7.1	31.2	25.0	6.2	
95	30.2	23.0	7.2	36.2	29.0	7.2	
120	34.0	26.0	8.0	41.2	33.0	8.2	
150	38.0	30.0	8.0	45.2	36.0	9.2	
185	42.0	33.5	8.5	49.8	39.0	10.8	
240	—	—	—	55.8	43.0	12.8	

Table 17

Number of Scribe Marks on Joint Sleeves for Different Conductor Sizes

Size of Grade A aluminium wire, mm²	Number of scribe marks	Size of Grade AC steel-cored aluminium wire, mm²	Number of scribe marks
16-35	6	35	14
50-70	8	50, 70	16
95-185	10	95	20
240	12	120, 150	24
—	—	185	26
—	—	240	2×14

placed, hand-operated pump *2* with a plunger 12 mm in diameter, and a suction and a delivery ball valve, tank *3* containing the working fluid (2-3 l of spindle oil), valve *4*

to discharge the working fluid from the press back into the tank, and piping *5* between the press and the pump.

When much work has to be done, a mechanized unit arranged on the same principle and powered by the engine of

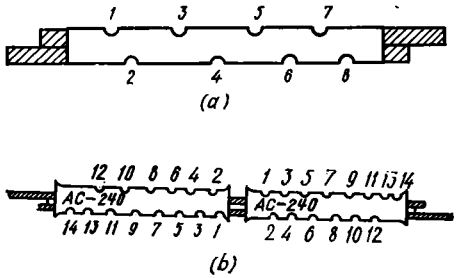


Fig. 159. Conductors jointed by crimping
(*a*) with one joint sleeve; (*b*) with two sleeves

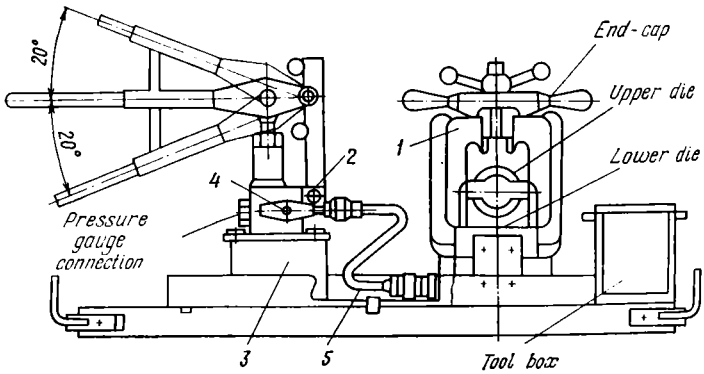


Fig. 160. Hydraulic press unit for jointing conductors by compression

a truck is used. The unit is stocked with sets of paired dies. Each pair of dies is stamped with the conductor size it is intended for and the ordinal number.

Before jointing, the conductors are arranged as they should be strung on the supports, the ends are cut square, cleaned, etc. The bore and length of the joint sleeve should also be

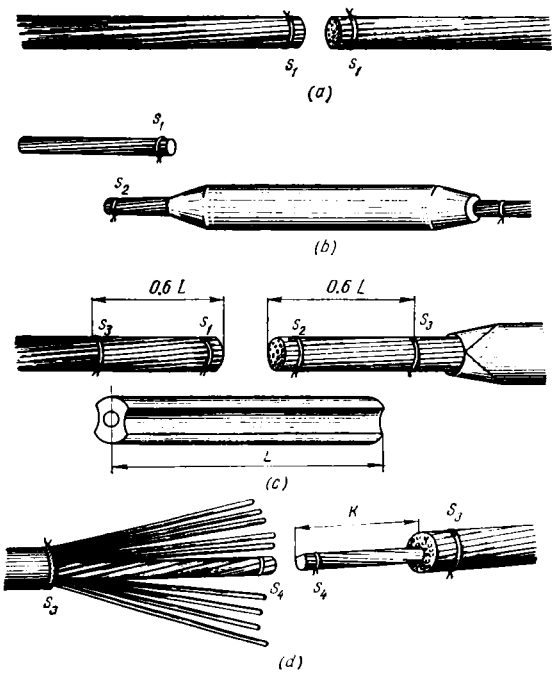


Fig. 161. Jointing conductors by compression

a) application of servings S_1; (*b*) application of serving S_2 and fitting of aluminium sleeve; (c) application of servings S_3; (*d*) exposure of steel core

checked against the working drawings. The tolerances are $\pm$ 5.0 mm on the length of the sleeve, $\pm$ 0.5 mm on its inside diameter, $\pm$ 0.5 mm across the large axis, and $\pm$ 0.2 mm across the small axis.

Sleeves are made of aluminium for use on the aluminium strands and of steel for use on the steel core.

Once checked, the conductor ends and the joint sleeve are thoroughly cleaned and coated with a slushing compound. Servings of wire (S_1 in Fig. 161*a*) are then applied, the aluminium sleeve is slipped on, say, the right-hand conductor end, wire serving S_1 is loosened and pushed along the conductor out of the way beyond the sleeve, and another serving

of wire S_2 is applied to the end of the conductor projecting from the sleeve (Fig. 161*b*). The sleeve is backed in turn about 0.8 to 1 m from the conductor end.

Next, servings of wire S_3 (Fig. 161*c*) are applied at 0.6 the steel sleeve length of each conductor end, servings S_1 and S_2 are removed, the aluminium strands are spread out, cut to half their thickness, and broken off. Now servings S_4 are applied to the ends of the steel cores bared for the length K (Fig. 161*d*). The steel core ends are de-burred, cleaned with petrol, and given a coat of slushing compound. The steel core is then pushed into the steel sleeve, with servings S_4 first backed and then removed.

The steel sleeve with the conductors pushed into it, is set on the lower die so that the working face of the latter is at the centre of the joint, and the flutes on the steel sleeve sides are vertical in respect to the die base. Then the upper die is installed.

The entire assembly is placed in the press, with the piston in its lowest position. The steel joint is compressed beginning at the centre of the sleeve and proceeding towards its ends. The joint should be moved each time so that the working face of the die overlaps the previously compressed section by 6 to 8 mm. On each grip the dies should be brought within 0.1 to 0.3 mm of each other, as checked with a feeler gauge. Should the sleeve be bent by compression, it can be straightened by turing the lower die through 180°, the concave side downwards.

After compression, the sleeve is filed to remove possible burrs and given a coat of petroleum jelly, as are the adjacent portions of the conductors.

Next the aluminium sleeve already slipped over the conductor is compressed. The dies in the press are replaced by those for aluminium. The joint is compressed beginning where the steel sleeve ends and proceeding first towards one end and then towards the other away from the centre which is left uncompressed. To prevent the conductor from bulging at the ends of the aluminium sleeve, temporary servings of soft wire should be applied 15 to 20 mm away from its ends.

The aluminium sleeve is compressed in the same manner as the steel one.

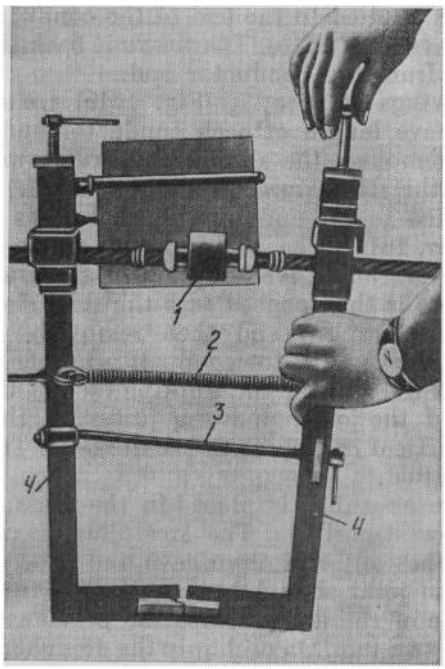


Fig. 162. Tongs for jointing conductors by thermit welding

The procedure for jointing earth wires is the same as for conductors.

To prevent corrosion, minimum ground with drying oil is applied where the conductors and earth wire come out of the joint sleeves.

Thermit joints. The ends of the conductors to be joined are thoroughly degreased by wiping them with a rag moistened with petrol or acetone, cleaned with a wire brush, and filed square. Before filing, tight servings of soft binding wire should be applied.

Prior to clamping the conductor ends with a pair of tongs (Fig. 162), the latter should be checked for easy motion without gripping. The tongs are then clamped together and locked with catch *3*. Thermit cartridge *1*, with the conductors pushed into it, is placed in the tongs. The conductors should

be firmly clamped in the tongs and pushed into the cartridge as far as they will go. The cartridge is placed between the jaws of the tongs, with its cut-out facing upwards. Once the entire assembly is properly positioned, catch *3* is released, and the conductors being jointed come under the action of springs *2* of the tongs.

To prevent the molten metal from flowing out in the course of welding, the ends of the cartridge are sealed with asbestos cord. Then a burning thermit matchstick is held to the cartridge side marked with red paint or labelled. The ignited thermit charge burns and melts the aluminium insert put in the cartridge. The ends of the conductors being joined also melt, give way, and are hence brought together by the action of spring *2* of the tongs to become a single welded piece. At the time of welding it should be seen that both jaws of the tongs advance at the same rate. Otherwise, the lagging jaw should be advanced manually.

On completion of welding, the joint is allowed to cool down, whereupon the tongs are withdrawn, the slag is removed, and nippers are used to cut off the fragments of the cartridge (mould). The welded joint is cleaned with a wire brush, and its quality checked.

On power-line spans, the conductors to be joined by thermit welding are relieved of mechanical load by locating their ends in a loop. Thermit welding providing a stable electric contact is used jointly with compression which gives the required mechanical strength.

The chief advantage of jointing conductors by thermit welding is reduced maintenance costs, since thermit joints do not have to be regularly inspected in the course of line operation.

Dead-ending, tensioning, and transposition of conductors. In securing the conductors to the anchor support from which the tensioning is to be started, tension clamps are first put on the conductor. Tension clamps may be either of the bolted type or of the compression type.

Once the clamps are in place, they are attached to the respective tension insulator strings and lifted, together with the conductor, onto the anchor support with a rope passed over a block suspended from the support cross-arm. The end of the rope is attached to the pulling mechanism which may

be a winch, tractor, or truck. The lifting rope should be made fast to the third insulator from the top of the string.

With the conductors secured on the first anchor support, the conductor at the other end of the anchor span is attached to a stringing clamp, passed over a snatch block, and lifted,

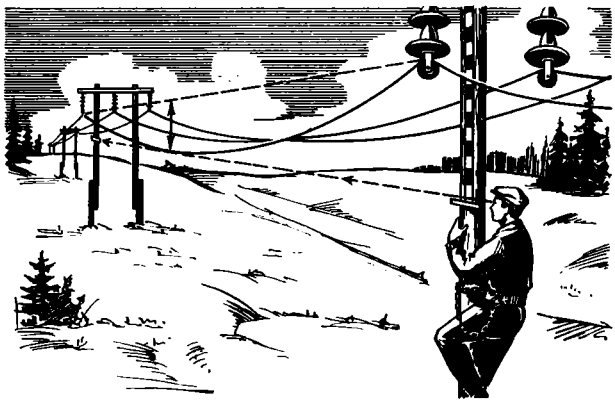


Fig. 163. Adjustment of sag

along with the latter, onto the support cross-arm. The conductor end carrying the stringing clamp is made fast to the pulling mechanism.

Next the sag is adjusted with the aid of sighting battens (Fig. 163). Sags are sighted in two spans, the farthest from the pulling mechanism and the nearest to it. Those who do the sighting should have field glasses. The required sag is adjusted first in the farthest and then in the nearest span.

It should be noted that sag tables give a reduced sag in order to allow for its increase due to sleet or heavy wind loading, etc., so that the necessary clearance will not be decreased.

At the second anchor support the tension conductor is marked with a serving applied under the insulator string attachment point determined for the selected sag. The conductor is then lowered to the ground, and a distance equal to the length of the tension string and clamp is laid off along

the conductor back from the serving, thus locating the tension clamp. The clamp is fitted on the conductor in the same way as at the first anchor support, whereupon the tension string is lifted, together with the conductor, onto the support and made fast to its cross-arm.

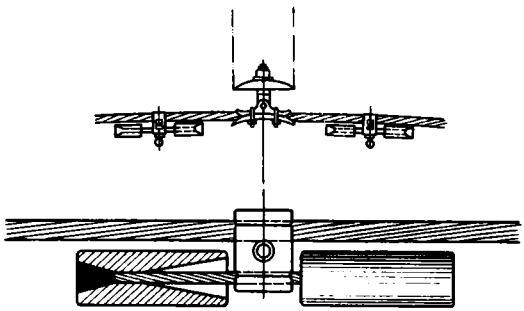


Fig. 164. Vibration damper mounted on conductor

The tension clamp may be secured to the second anchor support without lowering the conductor to the ground, using a telescopic tower.

As mentioned above, conductors are passed over snatch blocks to be reeled out. After a conductor has been strung, the snatch blocks are replaced by suspension clamps. This operation referred to as transposition of conductors had better be performed from a telescopic tower.

It should be remembered that before aluminium or steel-cored aluminium conductors are clamped, they should be wrapped in a strip of aluminium about 10 mm wide and 1 to 1.5 mm thick.

At the same time as the conductors are transposed, vibration dampers (Fig. 164) are installed to suppress vibrations set up in the process of line operation.

46. Safety Rules for Installation of Conductors and Earth Wires

Prior to installation of conductors and earth wires, the wire-stringing equipment and tools must be inspected, tested, and made fully serviceable.

Those working on supports must wear safety belts reliably secured to the support. Electricians should never be allowed to climb angle-suspension supports and work on them within the interior angle formed by the bend of the line, as they may be struck by a conductor going loose.

While insulator strings and conductors are being lifted on supports, or conductors reeled out and strung, nobody should be allowed to stand under the supports or conductors. Tools or line accessories should never be dropped from a support, nor a man should be allowed to descend down a rope suspended from the block used for lifting insulator strings and conductors.

As a thunderstorm comes up, all work on supports must be immediately discontinued.

47. Lightning Protection of Overhead Lines

Power transmission lines are protected against lightning discharge by means of an earth wire installed along the line and connected to a safety earth. With a support mounted on

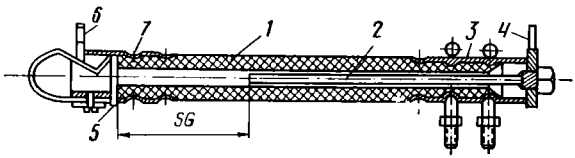


Fig. 165. PT protective tube (*SG*—spark gap)

prefabricated reinforced-concrete foundations, the earth wire is connected to an earth electrode through the support metalwork.

The earthing connection can be made up of earth electrodes fabricated of steel angles. Two or three earth electrodes of this kind are tied into a grounding mat at each support.

Power transmission lines are also protected against lightning discharge by means of protector tubes. The design of the PT protector tube is shown in Fig. 165. Fibre tube *1* is coated with bakelized paper and provided with steel ferrules *3* and *7* secured on the ends. Fixed in ferrule *3* are rod-shaped electrode *2* and clamp *4* to connect the earthing line.

Ferrule *7* accommodates flat electrode *5* with a centrally located hole and clamp *6* to attach an arcing horn of steel wire used to form an external spark gap (Fig. 166).

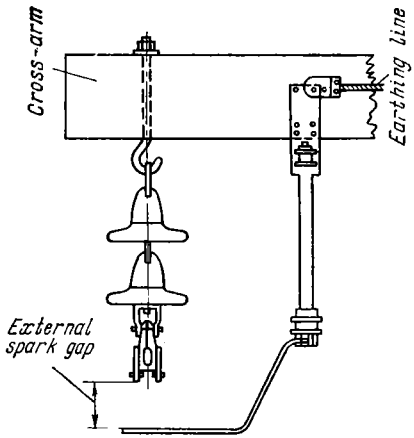


Fig. 166. Protective tube mounted on support

A protection tube should be so mounted that its base is at least 2.5 m above ground level. When it is impossible to observe this distance, special fencing must be provided.

Questions

1. What main elements is a power transmission line made up of?
2. What methods of mounting wood-pole, reinforced-concrete, and metal supports do you know?
3. What main safety requirements must be complied with in mounting power-line supports?
4. What is the procedure of assembling insulator strings used in the erection of power transmission lines?
5. What sequence is followed in reeling out conductors and earth wires?
6. What methods are used to join line conductors?
7. What is the procedure for mounting conductors and earth wires on supports?
8. What main safety rules must be observed while installing conductors and earth wires?
9. How are power transmission lines protected against lightning discharge?

PART TWO ● OPERATION AND MAINTENANCE OF STATION, SUBSTATION, AND LINE EQUIPMENT

CHAPTER 9

Organization of Operation and Maintenance

48. Scope and Principles

Electric power stations, substations, and power lines are intended for generating, transmitting, and distributing electric energy among users. These functions can only be performed provided all the equipment involved gives continuous, trouble-free service under specified operating conditions. To meet this requirement, the equipment has to be checked, attended to, trouble-shooted, operated under specified conditions, etc.

By the operation and maintenance of station, substation, and line equipment is meant all activity required to keep the entire system of power generation, transmission, and distribution in running order.

The objectives of operation and maintenance are to provide planned total output and supply at peak loads, to ensure continuity of power supply at a constant frequency and rated voltage, and to keep power costs at a minimum. Yet the specific features peculiar to power generation place more stringent requirements on the operation and maintenance of electric power stations, substations, and power lines.

A distinguishing characteristic of power generation, transmission, and distribution is continuity which is due to the fact that electric energy is consumed at the same time as produced and cannot be stored. Electric power stations must generate, and electric power lines transmit, as much power as the user needs at the moment (with allowance made for auxiliary power requirements and transmission losses). The

demand for electric energy varies on both a daily and a yearly basis. Daily variations in power demand are usually predetermined by the daily load schedule. The maximum load occurring in 24 hours is referred to as the *peak daily load*, and the time when it takes place, as the *busy hours*. Similarly, the peak load can be determined over any period of time, e.g. the peak annual load, etc.

Electric power stations and supply networks should not only hit the electric output target, but do it according to a preset schedule and meet the peak demand. Hence, all station, substation, and line equipment should be rated for the peak load and made ready to give continuous, trouble-free service during the busy hours.

Another distinguishing characteristic of power generation, transmission, and distribution is that a number of electric power stations and many substations are for the most part interconnected (rather than operated separately) by power lines into an integrated system supplying power to the users throughout an economical region. Therefore, any trouble or fault at a specific point in the network or at any one of the stations will affect the performance of the entire system and may cause an interruption of power supply to the users. A power failure, even a small one, greatly impairs the functioning of industrial enterprises, electric transport, and municipal utilities. The operation of industrial enterprises is discontinued and, moreover, the breakdown in production process may result in a damage to the products on line and to the production equipment.

Power users are sensitive not only to power failures but also to variation from the rated supply-line voltage and frequency. A voltage drop slows down electric motors abruptly, browns out electric bulbs, disturbs the normal operation of electrothermal plant, electronic devices, radio and TV sets, etc. A decrease in frequency varies the speed of electric motors, which in turn reduces the output of the driven machinery and often involves a breakdown in production process and hence the manufacture of defective products. Therefore, if a specific component of an electric power plant is out of order, or its performance is erratic, it should be quickly disconnected from the supply line in order to reduce the harmful consequences of the failure.

An important objective of operation and maintenance is to increase the cost-efficiency of electric power stations and supply networks by reducing the cost of energy production, the rate of power-generating fuel consumption, auxiliary power consumption, and transmission losses and by extending the equipment service life. Since electric power stations perform within a power system rather than individually, it is not only specific stations and transmission lines but primarily the entire system that must be operated economically. To achieve this goal, the load should be properly divided between electric power stations and generating sets, the required voltage level maintained at substations and in supply networks, and the station, substation, and line equipment repaired in accordance with the adopted schedule.

So the operation and maitenance of station, substation, and line equipment should be organized within the power system as a whole with the aim:

to realize the electric output target, to supply power according to the preset load schedule, and to meet the peak demand;

to ensure reliable performance of all the equipment involved and uninterrupted power supply to the users;

to supply power at rated voltage and frequency;

to keep the cost of system operation as low as possible.

49. Management Structure

The specific features of power generation impose increased requirements on the co-ordinated activities of the operating personnel of the entire power system and determine the structure of system management. The staff engaged in operating electric power stations and power networks is divided into *shift operators* and *maintenance men.* The shift operators keep watch on and attend to the electrical equipment in operation, perform the switching operations, take out equipment for repair and put it back in service after repair, put stand-by equipment in service when required, adjust and record the operating conditions, quickly remedy any abnormal conditions, and eliminate an emergency. The main-

tenance men carry out the running repair, overhaul, and routine tests of the equipment.

An electric power station is headed by the director to whom the chief engineer, shift engineers, and all departments and sections report. The shift engineer on duty reports to both the director and the power system dispatcher.

The power system dispatcher on duty co-ordinates and directs the performance of all the stations, substations, and power networks in the system. Aside from the station shift engineers, under his direct orders are line dispatchers, technicians and electricians at substations and hence all operating personnel. Thus each member of staff reports, while on duty, to both the chief operator and his immediate superior depending on whether operation or maintenance is concerned. This duality does not lead to conflicts due to precise differentiation of functions. The operating personnel must strictly follow the instructions and directions of the management staff with respect to equipment maintenance, while the management staff must not interfere in the orders given by the chief operator with respect to operations.

The electrical equipment of all the departments of a station is maintained by the station's electrical maintenance department. The electrical maintenance department is in direct charge of some of the equipment such as the switchgear equipment, transformers, and control board, and only services other equipment, including the electric motors in the various departments. The electrical maintenance department is also responsible for the electrical part of the turbogenerators, while their mechanical part is under the supervision of the turbine department personnel.

The work of the electrical maintenance department operating personnel is supervised by the shift superintendent who has the control board attendant and floating electrician under his orders.

The shift superintendent is fully responsible for operation of all equipment in his charge during his period of duty. He directs the elimination of any abnormal conditions and breakdowns in the equipment, and makes periodic rounds of the equipment.

The control board attendant keeps constant watch on operation of the station generators and adjusts their loads to

the orders received from the chief operator. He also watches the power transformers and lines, the storage batteries and their chargers.

The floating electrician makes rounds of the various departments of the station, remedies any troubles in operation of the electric motors, lightning circuits, etc.

The maintenance of substations is organized according to their location and importance within the power system, and the degree of automation. There is always a shift on duty at large, district substations as well as at stations. The shift normally consists of two men: the shift superintendent and floating electrician. At small substations, not equipped with remote-control facilities, provision is usually made for the duty personnel to remain at home so that it takes fewer men to perform the functions. The maintenance of automated and remotely controlled substations is centralized; they have no permanent duty personnel and are serviced periodically, as the need arises, by the power circuit district personnel who attend to several substations.

Questions

1. What is meant by the operation and maintenance of electric power stations, substations, and power lines?
2. What objectives are pursued by the operation and maintenance of station, substation, and line equipment?
3. What specific features are peculiar to power generation, transmission and distribution?
4. How is the management of an electric power station organized?
5. What responsibilities do the operating and maintenance personnel of electric power stations and networks have?

CHAPTER 10

Operation and Maintenance Activities

50. Operation Activities

Station, substation, and line equipment is operated by duty personnel working in shifts. Each shift superintendent is fully responsible for operation of all equipment in his charge during his period of duty. Provision is made for round-the-clock attendance, with a new shift superintendent taking over duties to relieve his colleague whose shift is over. Each shift superintendent must be well aware of the condition of the equipment at the beginning of his shift. The change of the shift is therefore an important moment in the work of the operating personnel and the procedure is as follows.

The new shift superintendent, before taking on duty, is obliged to inspect the equipment, to see what equipment and circuits are switched in or out, and to obtain information about the operating conditions. Special emphasis is placed on the major and more vital units, such as the generators, power transformers, and high-capacity motors. In taking over, the new shift superintendent should learn which units require special care, what equipment is in stand-by and what equipment has been taken out for repair. He should also read the notes in the log book to learn what changes have been made and what abnormalities occurred since his last time on duty and what orders have been given by the operator in charge.

The new shift superintendent takes over the keys, tools, instructions, and the log book in which the man leaving duty signs off and the man taking on duty signs in.

The relieving attendant should inform his chief operator of any abnormalities he has detected. The relieved attendant should report to his shift superintendent of the condition of the equipment when he hands over duty.

The change of the shift cannot be performed while an emer-

gency is being eliminated, switching operations carried out, or some equipment switched on or off. The work in progress should be completed by the man still on duty. This requirement adds to his personal responsibility for his actions during the period of duty. Besides, changing the shift while eliminating an emergency could delay the renewal of normal operation because the new attendant cannot grasp the situation at once.

The chief responsibility of duty personnel is to supervise the performance of the equipment in their charge and attend to it during their period of duty. These functions are performed by making rounds of the equipment. Periodic inspections reveal faults which may develop during operation and make it possible to take timely measures to remedy them. In most cases faults develop gradually rather than at once and, on a close examination, can be detected at an early stage. Thus, for instance, if a bearing becomes faulty, the electric motor starts to vibrate or the bearing heats up excessively. Loose contact joints heat up intensely, which is indicated by the changing colour of the thermosensitive film glued on to current-conducting parts at the contacts. When heated, the film varies in colour from bright red to dark red, then to cherry-red, and finally to black. The change in colour can be easily seen by the attendant who takes timely measures to eliminate the trouble that has caused excessive heatup.

While inspecting the equipment, attention must be paid to any changes in its condition no matter how small they appear, to fine cracks on the insulators, abnormal vibration of specific parts, unusual sounds, slight heating, arcing, an irregular corona displayed by a current-conducting part, etc. This must be done in order to prevent serious defects.

Of prime importance is careful maintenance of the equipment and upkeep of the premises, adherence to the operating and maintenance instructions. The premises must be kept clean, for dusty insulation is more liable to wear; ingress of dust and dirt between the rotating members impairs their performance. Great care must be exercised to see that the bearings are properly greased, and the generators, transformers, electric motors, and circuit breakers appropriately cooled. Inadequate cooling of a unit immediately results in its overheating which makes its service life much shorter.

Heating above the permissible temperature is most detrimental to the insulation of electrical equipment thus subjected to accelerated ageing, and severe overheating may cause the disrupture and breakdown of the insulation. A rise in the temperature of detachable contact joints adds to the oxidation of the surfaces in contact and raises the contact resistance, which is followed by a still stronger heatup.

Excessive heating may be due not only to insufficient cooling but also to overloading the equipment. The operating personnel on duty is also responsible for maintaining the proper operating conditions of all equipment in their charge.

The operating conditions of the equipment must comply with the preset load schedule, the directions of the operator in charge, and the requirements of the operating instructions and equipment duty charts. The operation of the equipment must be as dependable and economical as possible.

The economic performance of a plant depends on the correct distribution of load between the units operated in parallel, the number and connections of such units, and some other factors. If the load is reduced, it may be good practice to have fewer units in operation, since the power losses will be accordingly smaller. The number of units operated at a time must be selected, however, with regard to the reliability of power supply. Therefore, the number of the house transformers at an electric power station is selected so as to ensure uninterrupted power supply rather than for reasons of economy.

Of great importance to the more reliable and efficient performance of electrical installations and the improved quality of the power supplied are the automatic and remote control facilities which must be invariably in use. Their importance is still greater in the event of an emergency or otherwise faulty performance of electrical installations.

The proper operating conditions of a plant are easier to maintain with a signalling system by means of which the operators on duty are warned of abnormal conditions, and the operators having their work stations widely separated communicate with one another. To make sure that the signalling system is in good condition, the duty personnel must regularly check all signalling devices for proper operation. The test intervals are specified in a special instruction. The

testing is usually done at the time of changing the shift.

The most involved and binding are the activities of the duty personnel aimed at eliminating the abnormal conditions due to a fault or equipment breakdown. Abnormal conditions of this kind usually occur all of a sudden and require prompt action of the operator in charge.

The operator should make it his first business to clarify the nature of emergency. In so doing, he is assisted by the warning devices and alarms, and the reports of his subordinates. Then he should quickly, yet without unnecessary haste, take all prescribed emergency measures to eliminate the trouble and inform the chief operator of the trouble and the steps taken. For an emergency to be successfully eliminated, the operator on duty must have a perfect knowledge of all equipment in his charge, its arrangement and operating conditions, and of the pertinent instructions.

To train duty personnel to cope with emergencies, so-called mock-emergency exercises are periodically conducted and followed by a detailed analysis of the actions of each operator.

The best way to eliminate an emergency in a quick and faultless manner is to equip electrical installations with a variety of reliable automatic protection devices. The introduction of automatic circuit reclosers, automatic transfer circuit-breakers, devices for automatic off-loading at reduced frequency, and those for automatically building up the excitation of generators and synchronous motors has made it possible to eliminate an emergency and its consequences much faster, to raise the reliability of power supply to the users, and to facilitate the work of operating personnel in coping with emergencies.

Each emergency is thoroughly investigated to reveal all the shortcomings in operation of the plant that have caused the trouble. It is also found out whether the emergency measures taken by the operators are correct, and how good is their training. Basing on the results of the investigations, measures are planned to get rid of the revealed shortcomings.

Operating personnel is also responsible for switching operations performed to make a change in the connections of an electrical installation. This important question is dealt with in Chapter 11.

51. Scheduled Preventive Maintenance

While electrical equipment is in service, its components brought into operation are subject to progressive wear, the insulation to ageing and degradation, and the contact joints are impaired. Scheduled preventive maintenance is essential if station, substation, and line equipment is to be kept in good order.

Under the system of scheduled preventive maintenance adopted for electrical installations, specific pieces of equipment or whole circuits are taken out of service according to the approved schedule before they may be rendered inoperative by faults. The equipment taken out of service is inspected, checked, and tested to determine its serviceability. The worn parts and components are replaced or restored.

Scheduled preventive maintenance is subdivided into *routine repairs* and *overhauls.*

The objective of routine repair is to maintain the equipment in running order, for which purpose it must be kept clean, small defects detected during inspection must be eliminated, bearings greased at the proper time, and oil-filled units topped up. Routine repairs are usually carried out without opening the equipment.

To restore or replace the worn parts of the equipment and make it serviceable for a long time to come, the equipment is overhauled. The equipment under overhaul is opened and disassembled, inspected externally and internally; all its assemblies and parts are examined and thoroughly cleaned of dirt and dust, the damaged and worn parts replaced or restored, and the insulation reconditioned.

What is more, the manufacturing defects revealed in operation are often eliminated in the course of overhaul, the equipment is modernized, and specific design modifications are made to improve the reliability and efficiency of equipment performance. Because of this, not only the overhauled equipment is reconditioned, but its characteristics may as well be improved over those specified by the manufacturer.

To reduce the equipment downtime, an overhaul should be preceded by a meticulous preparatory work. An equipment overhaul sheet is drawn up in advance, as are appro-

priate task schedules, taking into account the defects detected in service. All materials and spares, tools and fixtures, and materials-handling facilities required for overhaul are prepaired, and a suitable work station equipped. The maintenance team assigned to the job is thoroughly briefed and acquainted with the drawings, service and shop instructions, and the overhaul schedule.

The work station should be fitted with the required appliances and materials-handling facilities, kept clean, amply lighted and ventilated. Compressed-air, acetylene, and oxygen lines should be taken to the repair area which should also be provided with electric outlets for welding equipment.

The above measures increase the labour productivity during overhaul and improve the quality of repair work which in turn raises the reliability of equipment performance and prolongs the time between overhauls. Repair work involves exacting quality inspection, assembly-by-assembly acceptance of the repaired items, and necessary testing. On completion of repairs, records should be executed on standard forms.

Repairs to station, substation, and line equipment are carried out by either the *local maintenance personnel* or a *central repair agency*. In the latter case the number of maintenance men on site is reduced to a minimum or there is no maintenance personnel at all, and repairs are done by field maintenance teams sent by the central repair agency. Under such a scheme stations, substations, and lines can be staffed with much fewer men. Substation and line equipment is mainly repaired by central repair agencies, the more so, as most substations are either unattended or attended by persons remaining at home. As for electric power stations, routine repairs are usually carried out by the stations electrical maintenance department, and overhauls, by a central repair agency.

52. Approval and Routine Tests

Electrical equipment installed in place is put through *approval tests* to make sure that it is in good order and fit for service. During, after, and between overhauls and at the time of routine repairs, electrical equipment is subjected

to *routine tests*. The extent, standards, and time of approval and routine testing are specified in compliance with the pertinent regulations and operating instructions.

Routine tests are of great importance for improving the reliability and efficiency of equipment performance. Routine tests enable one to detect in good time weak spots in electrical equipment and to repair the faulty parts. Regular routine tests prevent unexpected troubles and hence possible power failures. Fault rate has been greatly reduced due to routine tests.

When electrical equipment is inspected and repaired, many of the hidden defects and incipient flaws may remain unexposed for lack of observable symptoms, as is frequently the case. Routine tests offer a means for making a more comprehensive check on the condition of the equipment and its main components, such as the mechanical linkage, magnetic system, current-conducting members with their contact joints, and insulation.

The testing of the mechanical components most accessible to inspection amounts to measuring the travel of the movable parts, clearances, circuit-breaker make and break time, vibration of the frame and bearing. These measurements enable one to check whether the mechanical components of the equipment are properly installed and adjusted. It is important to test-operate the mechanism being checked under adverse conditions: to close and open circuit breakers with the control current below and above the rated value, or at a reduced air pressure. A specific kind of test is testing the tanks of oil- and gas-filled units for leakage.

The main types of fault in magnetic circuits revealed by testing are plate-to-plate short circuits in the laminated iron cores of transformers, motors, and generators and turn-to-turn short circuits in windings. To check a magnetic circuit for serviceability, one should measure the no-load current of a transformer or electric motor or the no-load characteristic (no-load voltage versus field current) of a generator. If the magnetic circuit is out of order, the no-load current should be increased, with the voltage unchanged.

Contact joints are the weakest spot in current-conducting parts. An increase in the contact resistance measured across a joint is indicative of impaired contact. Besides, a faulty

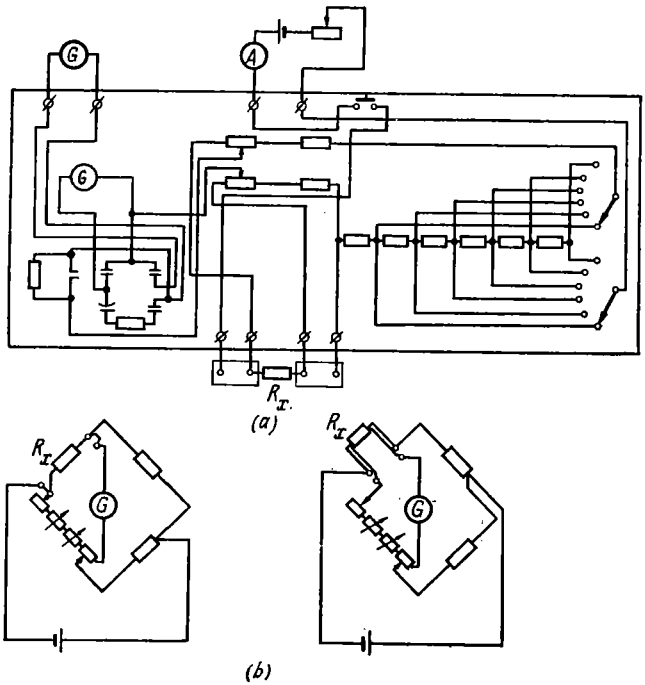


Fig. 167. Circuit for measuring contact resistance
(*a*) with МД6 Kelvin double bridge; (*b*) with P316 bridge; R_x—resistance being measured; *G*—galvanometer

contact joint heats up more than a sound one. As discussed above, strips of thermosensitive film are used to detect overheated contact joints.

Contact resistance is measured with an ammeter and a voltmeter or with an electrical bridge (Fig. 167). Bridge methods are more accurate for resistance measurement, because comparison is made directly with variable resistances. All wires used in setting up the test circuit should be connected with screw terminals. When an ammeter and a voltmeter are used, the circuit is completed by closing a knife switch, the instrument readings are taken, and the resistance is found as the quotient of voltage by current.

The electrical resistance of a sound contact joint must not exceed that of an equal length of the solid busbar more than by a factor of 1.2.

The most vulnerable element of electrical equipment is insulation. While electrical equipment is in service, its insulation loses gradually strength and dielectric properties on exposure to mechanical stresses, heat, and wide variations in electrical quantities. This process is referred to as *insulation ageing*. Chemical transformations that lead to insulation ageing are accelerated by heating. Thermal expansion of winding cores and vibrations generate mechanical stresses in the insulation of electric machines. A voltage, particularly in excess of the rated value, applied to the insulation is also detrimental to its properties and conducive to ageing.

Moisture and dirt are most harmful to insulation. Moisture fills cracks and pores in the insulation, thus providing a path for electrical breakdown, and contributes to ionization within the insulating material, which results in progressive failure. Since humidification and ageing cannot be revealed by examination, it is necessary to conduct insulation tests.

These involve measuring insulation resistance, absorption factor and dielectric losses, and conducting a high-voltage test.

Measurement of the insulation resistance is the simplest and most generally used method to check the insulation condition. The insulation resistance is compared with the results of previous measurements or the measurement data on similar units. Damaged insulation has a much lower resistance. Humidification and contamination also reduce the insulation resistance.

Insulation resistance is measured with a megohmmeter (Fig. 168) made up of a DC generator rated for 500, 1 000, or 2 500 V, a double-moving-coil ratiometer, and fixed series resistors electrically connected with each other. When the operating handle is cranked, the current developed by the generator flows through the two coils (making up the moving system) of the ratiometer, the series resistors, and takes the path through the unit tested for insulation resistance. The magnetic fields set up around the moving coils by the currents flowing through them interact with the field of the

permanent magnet in the instrument. The deflection of the moving system of the ratiometer depends on the ratio of the currents in the two coils.

The unknown resistance under test is connected in series with one of the ratiometer coils. With the generator furnishing a constant voltage, the current flowing through this coil is determined by the value of the resistance under test,

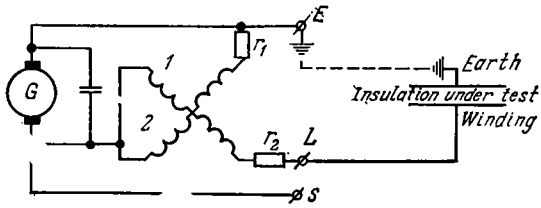


Fig. 168. Schematic diagram of megohmmeter

1—ratiometer coil connected in series; *2*—ratiometer coil connected in parallel; *G*—DC generator rated for 1 000 to 2 500 V; r_1 and r_2—series resistors; *L*—line terminal; *E*—earthing terminal; *S*—shielding terminal

while the current through the other coil is independent of it. The instrument error due to variations in generator speed is within 1% of full-scale value.

Insulation resistance may be tested with a megohmmeter only on de-energized circuits or equipment. Prior to testing, care should be taken to remove electric charges from the unit under test by connecting it to the earthing system for 2-3 minutes. The megohmmeter should be connected by high-resistance insulated conductors of the type used as magneto wires. The conductors must be terminated in test prods provided with nonconducting handles. While making measurements, the conductor from the megohmmeter terminal *E* is taken to earth, and that from the terminal *L*, to the unit under test, whereupon the generator is set in rotation by cranking the operating handle and the instrument readings are taken.

To determine the degree to which moisture has been absorbed by the insulation of the windings of generators, motors, and transformers, the absorption factor is measured. The values of insulation resistance measured with a megohmmeter are read from the instrument scale 15 and 60 se-

conds after the test voltage has been applied to the winding under test. The ratio of the values so obtained is called the *absorption factor.*

When insulation resistance is measured with a megohmmeter, the instrument pointer first deflects markedly towards zero, then starts moving to the right, and stops finally at a particular scale mark. The initial swing of the pointer is due to the flow of charging current into the winding due to its capacitance, and the further movement of the pointer is caused by a gradual decrease of the absorption current. The absorption current is caused to flow by the electric charges accumulated in the inner layers of laminated insulation. The effect of lamination becomes less pronounced and the absorption current falls off in less time as more moisture is absorbed by the insulation. With dry insulation, the accumulation of electric charges in the inner layers and the fall-off of the absorption current are slow processes. Because of this, the absorption factor of dry insulation may be as high as 1.5 to 2 and upwards, while damp insulation will have an absorption factor value close to 1.

The condition of oil-filled, compound-filled, and bakelized-paper insulators and terminal bushings can be assessed on the basis of their dielectric losses. But instead of dielectric loss which varies with the insulator size, it is more convenient to use what is known as the loss tangent which is equal to the ratio of leakage current I_l to the capacitive current I_c:

$$\tan \delta = \frac{I_l}{I_c}$$

The loss tangent is usually measured by suitabbe bridges. The loss tangent provides a check on the ageing of laminated insulating materials. With time they begin to separate and form voids where air can appear and moisture will ingress. These and other changes impair the quality of laminated insulation, and their dielectric losses increase. The loss tangent test is obligatory for all bakelized-paper, oil-filled, and compound-filled terminal bushings and insulators and for transformers.

All types of insulation must also be subjected to a high-voltage test with DC or AC voltage. The magnitude of test

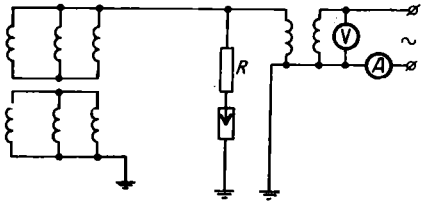


Fig. 169. Circuit for conducting high-voltage insulation tests by applying AC test voltage

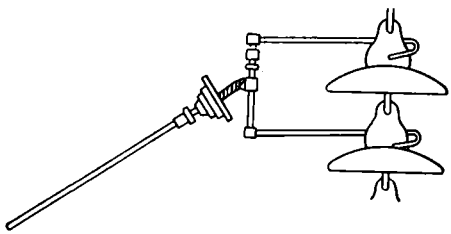


Fig. 170. Suspension insulators tested with special testing stick

voltage and the intervals at which the tests are performed on the various units of switchgear, as well as on the substation as a whole, depends on the operating voltage, type, and operating conditions of the insulation. The best results are obtained with AC test voltages, because in such cases the voltage gradients in the insulation are closer to those existing during actual operation. The duration of a high-voltage test is one minute.

The high-voltage test circuit is rather simple and the same for all electrical equipment of a power station or a substation. Fig 169 shows the circuit used for performing a high-voltage test on the main insulation of a transformer using AC test voltage. The windings should be tested one at a time, the remaining windings being shorted and earthed through the transformer core. The test voltage is applied to the shorted terminals of the winding under test from a special transformer having one of its leads earthed. The applied voltage is prevented from exceeding the test voltage by a protector tube.

Faulty suspension and support insulators are detected while they are in service by measuring the voltage gradient across the individual units of a string or support insulator with the use of a special testing stick (Fig. 170). The gradient will be lower across faulty units and higher across good ones.

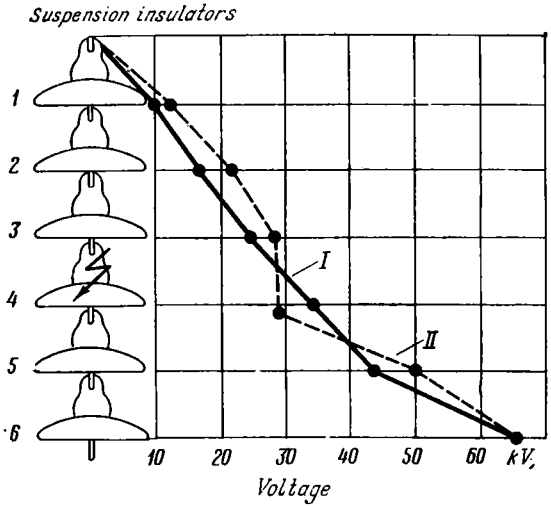


Fig. 171. Curves of voltage distribution along 110-kV suspension string
I – all insulators are sound; *II* – fourth insulator is defective

Fig 171 gives the voltage distribution curves for a good 110-kV suspension insulator string (curve *I*) and for the same string when the fourth unit is injured (curve *II*).

An insulator unit requires replacement when the voltage across it drops by a third to half of its normal share.

Questions

1. What procedure is followed by attendants when turning over and taking over duties?
2. What procedure is followed in changing the shift when an emergency is being eliminated, switching operations carried out, or electrical equipment switched on or off?
3. What steps should be taken by the attendants on duty in an

emergency, and what is required from them for an emergency to be coped with?

4. What is the purpose of a routine repair and an overhaul?

5. Why is electrical equipment put through approval and routine tests?

6. What test circuit is used to measure the contact resistance of a joint with the aid of an ammeter and a voltmeter?

7. What is meant by insulation ageing?

8. What instrument is insulation resistance measured with? Describe its circuit arrangement.

9. What circuit is employed to perform an AC high-voltage insulation test?

CHAPTER 11

Switching Operations

53. General

Switching operations are performed whenever it is necessary to make a change in the connections, take a piece of equipment out for repair or when emergencies arise.

Switching operations are the most responsible of the functions of duty personnel in electric power stations and substations. They are classed as *simple* and *multiple*. Switchings involving more than one connection are referred to as multiple.

For a correct switching a definite sequence is essential. As experience has shown, most of the gross errors in the performance of routine switchings are due to failure of duty personnel to follow the proper sequence. This is particularly true of simple switchings, well known to the attendant and successfully performed by him more than once. These are the opening of an isolator under load, application of voltage to a temporary safety-earthing set left unremoved from a place where work has been completed, opening of a wrong circuit breaker.

Basic switching rules. Switchings may be entrusted only to specially trained duty personnel. In plant where the isolators are not interlocked, all multiple and simple switchings should be performed by two men, one man doing the actual switching and the other seeing that the operation is performed correctly. The man supervising his mate in doing the switching shall be higher in rank and have a safety rating of Group IV as a minimum. The rating of the man performing the switching operation shall not be lower than Group III. The two men share the responsibility.

An electrician on duty having a safety rating not below Group IV is allowed to operate circuit breakers in factory-assembled switchgear and factory-preassembled transformer substations, and to perform simple switching operations in plant protected by interlocks against improper operation,

and all operations on switchboards and terminal blocks rated for 500 V and under.

Temporary safety-earthing sets should be applied and removed by two persons.

All switching operations in the switchgear of electric power stations and substations are performed on order received from the chief operator of the system or with his consent.

In plant operated at voltages above 1 000 V and not fully protected by interlocks, multiple switching operations are performed to written orders filled out on standard switching forms. The form contains a detailed assignment and specifies the individual steps of a given switching operation and their sequence.

54. Operation of Isolators

As a rule, isolators may be operated only after the power switch has interrupted the load current. The reason is that isolators have no devices to extinguish the arc striking between the contacts of the broken circuit.

To minimize the consequences of wrong operation of isolators, the following procedure has been established for an operator to observe should an arc strike.

For the worm-gear type of operating mechanism in which the isolator blade moves slowly, a closing stroke must be brought to completion irrespective of the arc. Should an arc strike on an opening stroke, the blade should be immediately reversed. As a result, in both cases the arc is shunted and extinguished.

For the lever type of operating mechanism by which the isolator blade cannot be reversed, any operation once started (whether closing or opening), must be completed under all circumstances in a resolute and quick manner.

Isolators may be used to make and break only the circuits specified in the pertinent operating rules.

55. Examples of Simple Switchings

The simplest switching operations include the connection and disconnection of underground cable and overhead lines, disconnection of motors, etc.

The following procedure has been adopted for opening bus and line isolators: the circuit breaker is opened first, then the line isolators and finally the bus isolators are opened. With this sequence, should a line isolator be used wrongly to interrupt the load current, the protective relays of this bus will trip the circuit breaker open. Otherwise the switchgear busbars would be faulted.

When a line is to be energized, the bus isolators are closed first, then the line isolators and, lastly, the circuit breaker.

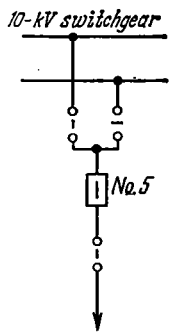


Fig. 172. Connections for taking 10-kV line circuit breaker out for repair

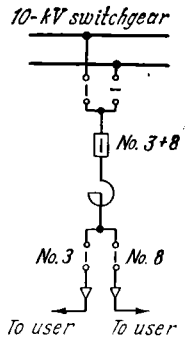


Fig. 173. Connections for switching out (for repair) one of two 10-kV cable lines fed in parallel through one circuit breaker

A wrong sequence with a bus isolator will cause a more severe breakdown than with a line isolator. Typical simple routine switchings done to take a piece of equipment out for repair or put it into operation are discussed below.

Switch-out of a 10-kV cable line circuit breaker for repair (Fig. 172). A call from user informs that line No. 5 has been disconnected by the circuit breaker and line isolators at his end.

The procedure for the operators:

check line No. 5 for load current with an ammeter;

open the circuit breaker of line No. 5;

hang a "DO NOT OPERATE — MEN AT WORK!" notice on the operating-mechanism control lever of the No. 5 line circuit breaker;

depending upon its type, check the position of the breaker as indicated by the telltale or the contacts to make sure that the No. 5 line circuit breaker is open, and then de-energize the operating mechanism;

use a detector to check that the line isolators on line No. 5 are deenergized and open them;

disconnect the No. 5 line bus isolators from the operating bus and check to see that they are fully open;

padlock the operating mechanisms of the opened No. 5 line isolators;

check that no voltage exists at the terminals of the No. 5 line circuit breaker and attach two temporary safety-earthing sets, one on the bus side and the other on the line side.

Take-out for repair of one of two 10-kV cable lines using a common circuit breaker (the cell has fireproof barriers between the line isolators). To begin with, 10-kV cable No. 3 of line No. 3 + 8 should be disconnected at the user's end (Fig. 173). If the cable is longer than 10 km, its charging current must never be interrupted with the isolators.

The procedure for the operators (for cables up to 10 km long):

check the cable for load current with an ammeter;

open the No. 3 cable line isolators;

padlock the line-isolator operating mechanism;

hang a "DO NOT OPERATE — MEN AT WORK!" notice on the line-isolator operating mechanism;

inform the user that cable No. 3 has been de-energized, whereupon the user may, with due precaution, apply a temporary safety-earthing set, post the required warning notices, and carry out the necessary repair work.

Disconnection of a station auxiliary motor for repair (Fig. 174). The station's engineer in charge has ordered that the electric motor of district-heating pipeline pump No. 3 be taken off the line for repair. The motor is operated from a 3-kV factory-assembled switchgear.

The procedure for the operators:

give an order to the heat-power service department to put standby pipeline pump No. 4 into operation and take over the load from pump No. 3;

make sure that pump No. 4 and its motor operate normally;

switch off the motor of pump No. 3 and hang a "DO NOT

OPERATE — MEN AT WORK!" notice on the control lever;

de-enegize the operating mechanism of the circuit breaker of the No. 3 pipeline pump motor;

draw the circuit breaker of the No. 3 pipeline pump motor out of its compartment in the factory-assembled unit into the repair position;

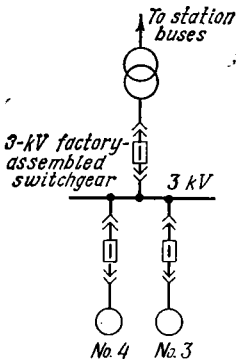


Fig. 174. Connections for taking station auxiliary motor out for repair

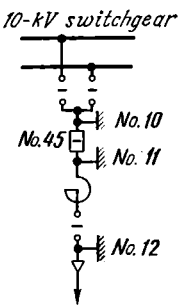


Fig. 175. Connections for switching 10-kV line back into operation after repair

check for absence of voltage, disconnect the supply cable from the motor terminals and short it;

take measures to prevent the motor from being rotated by the pump.

Connection of 10-kV line after repair (Fig. 175). An order has been received to switch in line No. 45 after repair.

The procedure for the operators:

remove temporary safety-earthing sets Nos. 10 and 11 from the circuit breaker and safety-earthing set No. 12 from the line isolators of line No. 45; also remove all warning notices and temporary guards;

check the telltale or the contacts to make sure that the No. 45 line circuit breaker is open;

unlock the No. 45 line isolator operating mechanisms;

close the bus isolators on the main bus side;

close the line isolators of line No. 45;

energize the No. 45 line circuit breaker operating mechanism;

close the circuit breaker;

inform the user that the voltage has been applied to line No. 45.

Questions

1. What basic rules are to be followed in performing switching operations on electrical equipment?
2. Why is it permissible to operate isolators only after the power (oil-immersed or air-break) switch has interrupted the load current?
3. In what sequence are line and bus isolators to be opened?
4. What is the procedure for taking a cable line circuit breaker out for repair?
5. What is the procedure for the take out for repair of one of two 10-kV cable lines using a common circuit breaker?
6. What is the procedure for switching in a 10-kV line after repair?

CHAPTER 12

Switchgear Maintenance

56. Inspection and Preventive Maintenance

The switchgear of an electric power station or substation integrates the circuitry of all main units, such as generators, transformers, and lines, into a single system. A fault in the switchgear will disturb the normal operation of one or more main units, which places heavy demands on switchgear maintenance.

Close supervision and care, scheduled preventive maintenance and routine tests are essential if switchgear equipment is to give reliable and trouble-free service.

Switchgear is supervised by making regular rounds of inspection on which all electrical equipment and switchgear premises are carefully examined in both indoor and outdoor substations. Inspection intervals are specified in the service regulations as follows:

attended substations (or those where the attendant on duty remains at home) should be inspected once a day; in addition, night inspections with lights off should be conducted at least once a month to reveal points of voltage or corona discharge, etc.;

unattended installations should be inspected at least once a month.

Each time a short circuit has been cleared the equipment should be inspected. Outdoor substations also require more frequent inspection in bad weather (thick fog, wet snow, sleet storms) or where the insulation is heavily contaminated by industrial waste. The purpose of additional inspections is to check the performance of specific switchgear components under extreme conditions.

All troubles and defects discovered during an inspection should be entered in an inspection log book and remedied as soon as possible. Switchgear equipment and premises

should not only be inspected but also maintaned in good repair.

On a round of inspection the attendant should pay attention to the condition of the switchgear premises. The rooms should be kept clean. Care should be taken to see that the windows are closed, and mostiure shut out, because the insulation of indoor switchgear is not designed for operation in a polluted and humid atmosphere. Animals and birds must also be prevented from entering the switchgear rooms, for their coming in contact with the current-conducting parts may result in a short circuit or earth fault. The partitions should be in good repair, and the openings and holes for cables sealed to prevent the spread of fire and smoke in the event of a short circuit.

Switchgear premises and equipment should be periodically cleaned of dirt and dust. Equipment is usually cleaned at the time of routine repairs.

All oil-filled units require close supervision and careful maintenance. The oil level in such units should be checked against the oil gauges which must be located so as to face the control aisles for the attendant to watch them without de-energizing the equipment. Should the oil level drop, the cause should be determined and eliminated as soon as possible, because the insulation is impaired and the circuit breakers become incapable of arc extinction on opening for lack of oil. Oil downflows on the housings of the units and grease stains on the ground beneath them are indicative of oil leakage.

In winter, if the temperature drops below that specified in the pertinent instructions, steps should be taken to heat up the oil in the oil circuit breakers lest the oil should become too viscous for the oil-immersed parts, and hence the movable contact blades, of the circuit breaker to move as fast as required for arc extinction on opening. Therefore, if the outer-air temperature is close to 25 to 30°C below zero, at which point oil viscosity increases markedly, the oil heater should be turned on.

The operating mechanism of a circuit breaker performs worse with reduction in the temperature due to the increased friction between the rubbing parts. Because of this the operating mechanisms of both oil and air circuit breakers

must be heated up when the temperature drops as low as + 5 to 0°C. In the latter case it is primarily the valve boxes and the distributor and control cabinets that must be heated. Other measures taken, at the approach of winter, to ensure the trouble-free performance of the operating mechanisms are to clean the rubbing parts of dirt and rust and give them a coat of cold-resistant grease and to fill the dashpots with an oil that congeals at a temperature 10°C below the lowest temperature observed in winter in a given region.

Special attention should be paid to air circuit breakers.

When indoor switchgear is inspected, it should be seen that the room is maintained at the proper temperature and adequately ventilated. The detachable contact joints must be checked for possible overheating as indicated by the strips of thermosensitive film provided for the purpose.

Of great importance to the trouble-free operation of an installation is that the standby equipment be always available for service. To make sure that it is in running order, it must be attended with as much care as the equipment being operated. Besides, the standby equipment should be periodically energized to check its readiness for operation.

57. Notes on Switchgear Repair

As mentioned above, all repair work involved in the maintenance of electrical equipment may be classed into routine repairs and overhauls.

Routine repair is carried out in order to remedy any defects detected during inspections and, also, to locate and eliminate the causes of specific troubles observed in service. Routine repair is performed as the need arises at the time specified by the chief engineer.

The scope of routine repairs to switchgear equipment is as follows:

a thorough visual inspection of the entire installation, cleaning of the equipment, and also cleaning of the premises;

checking and tightening of the fastenings and busbar clamps and joints; replacement of damaged insulators;

cleaning and grinding of pitted isolator contacts, lubricating of contacts with petroleum jelly, trial closings and openings of single-pole isolators, checking of the blades in

three-pole isolators for simultaneous closure, checking of operating mechanisms, adjustment and lubrication of pivot joints in isolators, tightening down of baseplates;

checking of roll-out chambers in factory-assembled switchgear units and replacement of fuses, where necessary;

checking of earthing system and connections;

checking of protective relays and measuring instruments;

sampling and replenishing of oil in all oil-filled apparatus.

Overhauls of switchgear units, including internal inspections, are scheduled at the following intervals:

for oil circuit breakers and their operating mechanisms, at least every three years, and air circuit breakers, two or three years. Depending on the breaker design, the number of operations it has performed, and the short-circuit power at the point of installation, the overhaul period may be extended. Unscheduled overhauls of oil and air circuit breakers may be necessary after they have cleared a few short circuits;

for isolators, earthing blades, short-circuiting switches, isolating switches and their operating mechanisms, at least every three years.

The remaining switchgear equipment is given an overhaul when the preventive maintenance work shows the need for it.

A typical overhaul will include the following:

an insulation test of bushings and internal insulation of circuit breakers, a check on the condition of their movable and fixed contacts;

a check on the attachment of the contacts, arc-control chambers, and deion grids and their replacement when necessary;

a check on the circuit breaker operating mechanism, the springs, bolts, nuts, cotter pins; a check on the condition of the breaker mechanism; trial openings and closings of the circuit breaker; a check on the breaker position indicator; adjustment of the breaker contacts for simultaneous closure; inspection of access covers, tanks, lifting mechanisms, gas vent assemblies, and safety valves; inspection of the auxiliary switch contacts and cams; cleaning and reassembly of oil gauges, oil replenishment, replacement, and purification;

a check on the movable and fixed contacts of load-breaking isolators for reliable attachment and simultaneous clo-

sure in all phases; a check for proper entry of all poles into their arc-control chambers; a feeler-gauge check for correct assembly of the arc-control chambers and for absence of gaps between the chamber halves; a check on the springs, bolts, nuts, and cotter pins; a check on the operating mechanism for overall condition and proper operation; a check on the automatic tripping of the load-breaking isolator in the event of a fuse blow-out; inspection of the auxiliary switch contacts and cams.

As power circuit breakers are rather difficult to overhaul, a more detailed discussion follows.

58. Overhaul of МГ-10 Oil Circuit Breakers

Disassembly. Insulating interphase barriers *2* (see Fig. 53) are removed first and then the gas manifold is detached from the circuit breaker and pushed aside to the cell wall where it

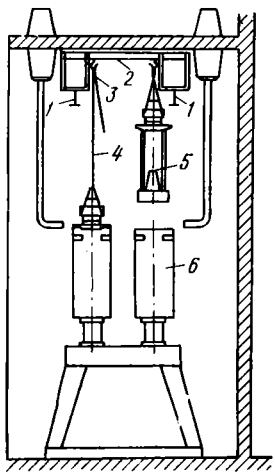


Fig. 176. Lifting of internal parts of breaker pot

1—cross beam; *2*—jumper beam; *3*—tackle block; *4*—sling; *5*—internal parts of pot; *6*—circuit breaker pot cylinder

is tied to the ceiling beams. In order that the gas manifold can be swung out of the way, its joints should be loosened, and the manifold turned about the inlet connection.

Next the busbars are disconnected from the circuit breaker, jumper beams *2* (Fig. 176) are placed on the cross beams, tackle blocks *3* are attached to the jumper beams and fur-

ther disassembly is continued as in the initial inspection prior to installation.

Repair of contacts and arc-control chambers. The contacts and arc-control chambers are repaired after the breaker has been disassembled. If the load-carrying contacts are fused

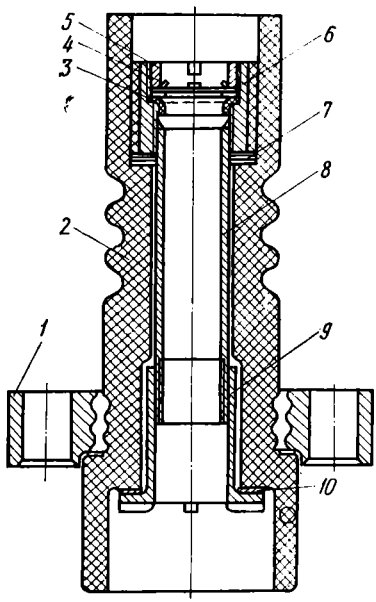


Fig. 177. Bushing insulator of МГ-10 (МГ-20) circuit breaker

1—flange; *2*—porcelain bushing; *3*—collar; *4*—contact ring; *5*—externally threaded round nut; *6*—upper flange of copper tube; *7*—washer of electrical pressboard; *8*—copper tube; *9*—lower flange of copper tube; *10*—aluminium washer

only slightly, the rough spots may be smoothed down with a file. All contacts which have considerably damaged surfaces should be replaced.

If the tips of the arcing contact rods show signs of slight fusing, they are filed smooth. When considerably fused, they should be replaced. To do so, the tip is clamped in a vise and the rod is screwed out of it. A new tip is then matched to the contact rod, their edges are trimmed at the joint,

and the tip is centre-punched at three points round the circumference of the joint.

When damage is detected on the cluster contact, it should be removed with a special spanner and disassembled. The contact fingers with slightly damaged surfaces are simply cleaned smooth, while those with a heavily pitted surface should be replaced, as should be all contact springs unfit for further service.

Repair of insulators. Bushings are inspected and wiped with clean soft rags moistened with petrol. Simultaneously leather collar *3* (Fig. 177) which serves as a seal in the upper portion of the bushing is examined. If the collar is damaged, it should be removed after unscrewing clamp nut *5* and contact ring *4*, and then replaced. The new collar should be installed so that it and the lugs of the contact ring fit closely the rod passed through the bushing. With the collar in place, nut *5* is tightened firmly.

Concurrently, the cemented joints between the insulators and their mounting flanges are examined and given several coats of glycerylphthalate varnish. Where some of the cement has crumbled out, it should be patched up. If an insulator has to be entirely re-cemented, it should be sent to a repair shop.

Support insulators should be replaced as described below. A 0.5-tonne hoist is suspended from cross beam *1* (Fig. 178) and the respective pot cylinder is lifted off after clamping ring *8* (Fig. 179) has been loosened. The bolts securing upper flange *5* are unscrewed and the insulator removed. Cap *7* is then taken off the insulator on clamping the latter in a vise to unscrew bolt *1* with a box spanner.

When mounting the cap on the shoulder of the insulator, upper flange *5* and gaskets *3* of electrical pressboard are first put in place, and then bolt *1*, complete with a steel washer and gaskets, is inserted and screwed tight. Gaskets of electrical pressboard are placed on lower flange *4* and the assembled support insulator is secured on the flange with bolts and lock washers.

Repair of gas vents. To take apart the gas vent system, lock nuts *9* (see Fig. 55) are screwed off the thrust bolts and the bolts are driven as far as possible into the oil-baffle pipe elbows, whereupon the oil-baffle pipes can be removed. The

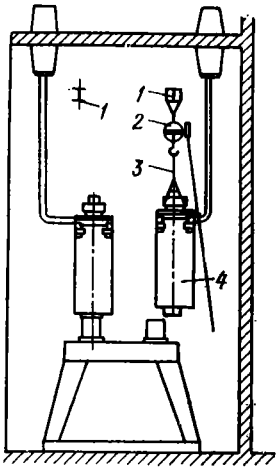


Fig. 178. Removal of breaker pot cylinder

1—cross beam; *2*—hoist; *3*—sling; *4*—breaker pot

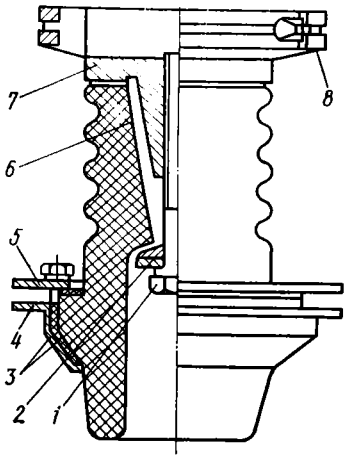


Fig. 179. Pot support insulator of МГ-10 (МГ-20) circuit breaker

1—bolt; *2*—steel washer; *3*—gaskets; *4*—lower flange; *5*—upper flange; *6*—porcelain insulator; *7*—insulator cap; *8*—clamping ring

porcelain balls or pebbles filling the inner space are then washed and dried, and all the other parts of the oil separator are cleaned. If porcelain insert *4* has to be replaced, it is essential to provide a tight joint between the insert and tube *2* of phenolic resin plastic.

The further assembly and mounting of the oil separator in the gas vent piping is carried out in the same order as when the circuit breaker is first installed. The joint between the gas vent pipe and base *1* should be sealed with phenol-formaldehyde lacquer to make it tight.

The circuit breaker is adjusted and prepared for service in the same way as in the course of installation.

59. Overhaul of МКП-110М Oil Circuit Breakers

Before an МКП-110М oil circuit breaker can be overhauled, the oil should be drained from its tanks by connecting the drain cocks to the oil piping with flexible hoses. After

the oil has been drained, the covers on tank manholes *6* (see Fig. 109) are unbolted to gain access to the internal assemblies and parts of the breaker for repair. A jack is then set up in the operating mechanism for manual closings and openings.

The bottom of each tank is covered with boards and a ladder is placed on them for interior work.

Before dismantling the arc-control chambers, the breaker is closed and opened manually to check the operation of the tie rods, levers, and the associated mechanisms. Next the jumpers connecting the arc-control chambers and the shunting resistors are removed and the latter are lifted off.

To provide access to the moving contacts in the arc-control chambers for inspection, screws *3* (see Fig. 111) are undone and shields *15* taken off. Then bolts *14* are unscrewed, and insulating rod *9*, the lower cover, spring *1*, the contact jumpers, flexible leads *2*, and lower contact *16* are removed as a single unit by turning it through nearly 90 degrees and pulling out of the arc-control chamber.

Whether or not the arc-control chambers have to be disassembled further depends on the condition of the contacts. If they are in good shape, the contacts may be cleaned and the inside of the cylinders of phenolic resin plastic wiped with rags soaked in transformer oil without removing them from the arc-control chambers. If the contacts are pitted and show a heavy deposit of carbon, the cylinder and fixed contacts have to be dismantled.

For this purpose, the bolts holding the retaining ring of the cylinder against the contact bushing are unscrewed leaving one bolt about which the ring and cylinder can be turned together so that the cylinder can be taken out, exercising utmost care not to bend the bolt or break the ring. The cylinder should be taken out of the tank and forwarded into a repair shop so as not to scratch the insulation. In the shop the cylinder should be put on a pad of soft material.

Next, bolts *6* are unscrewed, and cover *7* taken off the arc-control chamber. Now all the chamber parts are thoroughly examined, cleaned, and washed with transformer oil. The parts of phenolic resin plastic are examined for cracks

and lamination, and the cermet arcing plates, for reliable brazing to the contact jumpers.

Traces of pitting on the contact surfaces should be removed on a grindwheel or with a bastard file. The machined contact surfaces are checked for perpendicularity to the axis of the contact with a straight-edge, try square, and slide calipers. If the contacts have worn down in excess of 2 mm, they should be replaced. Where the copper-tungsten cermet (kirite) plates have to be replaced, they should be brazed to the circuit breaker contacts with the ПМЦ-36 brazing alloy using an oxyacetylene torch. The scorched and blackened insulating parts within the chambers are cleaned and given three coats of No. 4C oil varnish allowing each coat to dry at 15 to 20°C.

Before reassembly of the arc-control chambers, all the parts should be wiped with clean, lint-free rags, or, better, blown off with compressed air. After the arc-control chambers have been assembled, the contact jumpers fitted on the insulating rod are checked to see that they are free to move in the guide blocks of paper-based laminate and make contact with the fixed contacts.

If, during an overhaul, the jumpers on the insulating rod and the fixed contacts in the cylinder of phenolic resin plastic were moved out of their factory-adjusted positions, it is necessary to check the contacts in the cylinder for simultaneous closure and proper motion before completing the assembly of the chambers. The contacts should meet simultaneously accurate to within 1 mm.

During an overhaul, the insulating lift rods are checked for cracks, laminations, and other defects, for the strength of the joints between the rod and the end fittings, and for free movement in the guides. Defective rods should be replaced.

Concurrently, the lift rods and their guides should be checked to see that they have been properly suspended. Each lift rod should be plumbed, and the guide adjusted so that the radial clearance between the guide and the rod is 1 to 1.5 mm. The manufacturer's instructions permit light contact between the lift rods and their guides. The guides are then fastened at the top with bolts and C-type spring washers.

The contact rods should be cleaned of traces of fusion and carbon deposit. When pitted deeper than 2 mm, the rod tips should be replaced. At the same time the contact rods are checked for attachment to the cross-arm, and the stop screws, for tightness.

The terminal bushings of the circuit breaker are examined for cracks in the upper and lower porcelain shells and chipped spots on their surfaces. The porcelain is then wiped with clean, lint-free rags moistened with petrol.

The cemented joints between the porcelain shells and the bushing flanges are also examined and given several coats of air-drying varnish. Where local crumbling of the cement is detected, it should be repatched in place and given three coats of natural drying oil or varnish, allowing each coat to dry fully. When a terminal bushing requires complete recementing, it should be sent to a repair shop.

The terminal bushings are also checked for reliable attachment to the breaker top plate. For this, the fastening bolts should be tightened, giving a quarter-turn at a time to the bolt across the previous one. In so doing, it is necessary to see that the rubber gasket is good and properly placed.

The top of each bushing should be examined to see that the entry of the terminal rod is properly sealed. When a bushing has to be replaced, the arc-control unit is first removed, the bolts securing the bushing holder to the cast-iron casing of the current transformer are unscrewed, and the bushing is lifted off with a crane or some other hoisting device in the same manner as when installing an МКП-110М circuit breaker.

As part of an overhaul, the pebbles filling the oil separators are washed, the gas vents and valves cleaned, the relief valves checked for their membranes, and the oil gauges and the oil-filling and oil-drain cocks on the circuit breaker tanks are checked and cleaned. The tank insulation is also checked and repaired, if necessary, and the fastening nuts are tightened.

To prevent ingress of moisture through the coupling bolt holes in the breaker top plate, the manufacturer's instructions recommend that during an overhaul the spring washers should be replaced by flat washers and hemp packing coated with phenol-formaldehyde lacquer.

60. Routine Tests

All switchgear should be put through routine tests scheduled, in accordance with the appropriate codes and regulations, at the following intervals:

for circuit breakers, isolators, earthing blades short-circuiting and isolating switches, and their operating mechanisms, at the time of overhaul;

for cast-in-concrete reactors, coupling capacitors, and static capacitors, at least every three years;

for 6 to 10-kV pin-type insulators, busbar bridges, and ШТ-30 insulators, at least once a year; for ШТ-35, ИШД-35, and ОС-1 pin-type insulators, at least every two years. For the other units and suspension insulators, at least every six years;

for contacts, busbar joints, and equipment connections, at least every three years.

Should defects be revealed in the equipment, the test intervals are reduced.

The standby electrical equipment and the assemblies and parts stored in case of emergency should be inspected, tested, cleaned, lubricated, or greased every three years.

The extent of switchgear testing is as follows.

All terminal bushings in the structures containing organic matter are tested by measuring the loss tangent. This test is unnecessary for 35-kV bushings. When measured at 10 to 30°C, the loss tangent of bushings must not exceed the values specified in Table 18.

Switchgear equipment is tested for insulation resistance

Table 18

Loss Tangents of Terminal Bushings or Insulators

Type of insulator or bushing	Loss tangent, %, at rated voltage, kV			
	3-10	20-35	110	154-220
Oil-filled	—	—	2	2
Bakelized-paper	3	2.5	2	—
Bakelized-paper, compound-filled	3	2.5	2	—

under commercial-frequency voltage. For each bonded unit of a multi-unit support insulator and for each suspension insulator, the regular test voltage is 50 kV. Circuit breakers complete with terminal bushings and also current transformers should be subjected to high-voltage insulation tests at commercial frequency in accordance with the data presented in Table 19. The test duration is 1 minute.

Table 19

Commercial-Frequency Test Voltage for Circuit-Breaker Insulation

Breaker rating, kV	Test voltage for standard insulation, kV	Test voltage for low-duty insulation, kV
3	22	12
6	29	19
10	38	29
15	49	43
20	58	—
35	85	—
110	225	—
154	290	—
220	425	—

While testing circuit breakers, isolators, and busbar structure, the contact resistance should be measured and compared with the standard values or the results of earlier measurements.

Questions

1. What is implied by the supervision of a switchgear installation?
2. What operations are included in routine repairs to switchgear equipment?
3. What operations are performed in overhauling a switchgear unit? What overhaul period has been adopted for oil circuit breakers?
4. What is the purpose of putting switchgear equipment through routine tests, and what test intervals have been adopted for main switchgear units?
5. What troubles in the main types of circuit breaker and their remedies do you know?

CHAPTER 13

Power Transformer Operation and Maintenance

61. Transformer Inspection

The transformer is an electrical apparatus reliable in service and convenient to maintain. Transformer maintenance includes periodic supervision of its operation, timely inspection, routine repairs and overhauls, routine tests, and control of its temperature and load.

Regular inspection and trouble-shooting are vital to the efficient operation and maintenance of transformers.

Main and house transformers should be inspected daily without disconnecting them from the line, and all other transformers in attended installations (including those where the attendant on duty remains at home), once a week. In unattended installations the transformers should be inspected at least once a month and at transformer substations, at least every six months.

To prevent accidents, attending personnel should inspect a power transformer while standing on the threshold of the transformer cell or bay outside the guard barrier. The inspector may go beyond the guard only if the lower flanges of the bushings on the transformer tank cover are at least 2 m above floor level and the unguarded live parts above the passageway are at least 2.75 m above floor level for an operating voltage of 35 kV, and 3.5 m for a voltage of 110 kV.

Off-schedule transformer inspections are made when the ambient temperature has changed sharply, each time a transformer has been disconnected by its protective gear, or a warning signal has come from the Buchholz relay.

The points to be watched during an inspection of power transformers are:

the approaches and passages to the substation should not be obstructed; the fences, guards, doors, window and

ventilating openings, and the structure as a whole should be intact, and the roof should not be leaky;

the transformer tanks should be intact, no oil should leak at the tank cover joints, flanges; and drain cocks, the oil level in the conservator should be sufficient for the prevailing temperature, and the oil-filled bushings should be full of oil;

the oil sumps should be in working condition;

the transformer oil temperature should be accurately monitored by the (indicating Bourdon-tube) thermometers. In air-blast transformers, the cooling system is checked for proper operation: the oil and water circulation (where a water-cooled oil cooler is provided), the blow fan performance, and the oil temperature upstream and downstream of the oil cooler;

the bushings and lightning arresters should be intact; there should be no dust or dirt on their surfaces and on the tank;

the busbars and cables should be free from damage and any signs of heating at the contacts;

the lighting facilities, alarm system, and the spark gap fuses should be in working condition;

the earthing system and the fire fighting equipment should be in good order;

the conservator should be free to communicate with the transformer tank, which condition can be checked by draining some of the oil through the gauge cock and watching the oil level in the gauge glass drop;

whether or not much moisture and sludge has accumulated at the bottom of the conservator;

the continuous oil reclaimers and the thermosiphon filters should operate normally, and the dehydrating units should be charged with fresh silica gel.

Any troubles discovered during an inspection should be remedied at the earliest possible occasion; should an emergency or accident occur, the unit must be immediately disconnected from the line.

Power transformers should be taken out of service in the following cases:

loud and undulating humming and crackling can be heard in the transformer;

the temperature rise of the transformer is abnormal and continuously increasing at rated load and cooling conditions;

oil has been expelled from the conservator, or the safety membrane in the gas vent pipe has burst;

the oil has been leaking and its level has dropped in the gauge glass;

the oil has varied in colour (several shades of the colour scale);

the porcelain on the bushings is cracked or chipped, creeping charges have appeared on the surface, or traces of flashover have been found;

the oil contains carbon, moisture, and large amounts of mechanical impurities, or it has increased acidity, reduced breakdown voltage, and a flash point which is more than 5°C below that of the previous test; the insulation resistance has decreased by more than 50% of its original value or of the value stated by the manufacturer.

62. Transformer Oil Maintenance

The condition of oil is of particular importance to transformer operation, as it forms both the insulating and cooling medium of transformers.

In the course of transformer operation the oil subject to ageing loses its original properties. Besides, its properties are impaired by abnormal operating conditions. Local overheating, insulation breakdowns between the steel laminations forming the transformer core, poor contact in the tap changer switch or in the winding terminals under the transformer cover, and partial turn-to-turn short circuits in the windings result in oil decomposition.

The condition and quality of transformer oil are judged by its chemical, mechanical, and electrical properties: acidity, moisture and mechanical impurities content, suspended carbon content, viscosity, flash point, and breakdown voltage.

Increased acidity leads to deterioration of the transformer-winding insulation due to attack by acid.

Increased moisture content impairs the dielectric proper-

ties of the oil and causes humidification of the winding insulation.

Mechanical impurities hinder normal cooling of the transformer, foul the windings, and may also lead to a voltage flashover on the insulation as they can form a current leakage path.

Increased viscosity of the oil impairs transformer cooling because it decreases the rate of oil circulation and results in a higher temperature rise of the oil and the unit as a whole.

Reduced breakdown voltage may lead to a winding-insulation breakdown and failure of the transformer. Reduced breakdown voltage is a sign that the oil contains moisture and organic acids due to ageing.

Lowered flash point is indicative of oil decomposition due to local overheating, because in the event of ageing the flash point of the oil is slightly raised rather than lowered.

Relevant standards set the respective figures for the properties of oil, both fresh and used (Table 20), as well as the time intervals at which samples should be taken from transformers and other oil-filled apparatus. A knowledge of these standards is essential if such equipment is to be maintained efficiently.

Transformer oil should be subjected to laboratory tests at the following intervals:

oil from transformers and apparatus rated up to 10 kV inclusive: a proximate analysis at least every three years;

oil from transformers and apparatus rated for 10 to 35 kV inclusive: an electric strength test once a year and a proximate analysis at least every three years;

oil from transformers and apparatus rated above 35 kV: a breakdown test and a proximate analysis once a year;

oil from sealed transformers: a breakdown test every two years;

oil from oil-filled bushings: a proximate analysis once a year;

oil from a transformer or apparatus after an overhaul: a proximate analysis.

After an oil circuit breaker has cleared a circuit, a sample of the oil should be taken and tested for suspended carbon.

An *electric strength* test includes a breakdown test and a

Table 20

Properties of Transformer Insulating Oil

Oil property	Fresh oil	Oil in service
Breakdown voltage (min) for apparatus rated:		
up to 10 kV	35 kV	20 kV
from 11 to 35 kV	35 kV	25 kV
from 35 to 220 kV	40 kV	35 kV
from 220 to 500 kV	50 kV	45 kV
Moisture, mechanical impurities, suspended carbon	None	None
Flash point, °C (min)	135	Max 5° below initial value
Acid number (max) expressed in terms of potassium hydroxide content in 1 kg of oil	0.05 mg	0.4 mg
Viscosity, Engler units (max)		
at 20°C	4.2	4.2
at 50°C	1.8	1.8

determination of suspended carbon and mechanical impurities.

A proximate analysis includes determination of a flash point, electric strength, acid number, suspended carbon, mechanical impurities, and moisture.

To inhibit oil ageing and to keep its dielectric properties at a high level, the oil in transformers rated above 100 kVA should be *reclaimed*, i.e. reprocessed in thermosiphon filters and absorbers so as to restore it to its original condition. Thermosiphon filters and absorbers are filled with a granular sorbent (silica gel or alumina) capable of selective absorption of the products of ageing from the oil.

As the properties of oil deteriorate, it is cleaned periodically with the use of pressure filters, separators, and absorbers.

Ageing of transformer oil is accelerated by overheating. The service life of the oil in a transformer is halved if its temperature is 10°C above normal. When a transformer is in service, the maximum temperature rise of the top layers of the oil should not exceed 60°C above an ambient temperature of +35°C. However, if oil is to have a longer service life, transformers should be operated so that the top-oil temperature does not exceed 85°C. Large transformers have devices which set off an alarm when this temperature is exceeded.

63. Transformer Overloads

In the course of a day, and also depending on the season of the year, the load on a transformer will not remain constant, which brings about variations in the operating temperature of the transformer.

A winding temperature rise of 60°C (above the cooling air temperature) to some value below it reduces the rate of deterioration of the winding insulation and extends transformer service life. Therefore, the overloads should be limited so that transformer service life will be not shorter than 20 to 25 years. Transformer overloads may be *continuous* and *emergency*.

Table 21

Limits of Continuous Transformer Overloads

Load factor* (determined from daily load schedule)	Limits (%) and duration (h) of overloads					
	2	4	6	8	10	12
0.5	28	24	20	16	12	7
0.6	23	20	17	14	10	6
0.7	17.5	15	12.5	10	7.5	5
0.75	14	12	10	8	6	4
0.8	11.5	10	8.5	7	5.5	3
0.85	8	7	6	4.5	3	2
0.9	4	3	2	—	—	—

* Load factor is the ratio of the average daily load on a transformer to its rated power.

Table 21 summarizes continuous-load limits for all types of power transformer at different load factors.

The rule for determining the permissible continuous loading of transformers is as follows. A transformer may be overloaded continuously 1% above its rating in winter for each per cent that its maximum daily average load is below its power rating in summer, but not in excess of 15% altogether. The total permissible overload determined from the actual load factor and the summer underload must not exceed 30%.

All conventional types of self-cooled oil-immersed transformer may be allowed to carry emergency overloads for the period of time needed to bring in a standby unit, irrespective of the previous load, ambient temperature, and the transformer location. The limits and duration of emergency overloads are as follows:

Current overload, %	30	45	60	75	100	200
Permissible duration, min	120	80	45	20	10	1.5

For dry-type transformers the permissible limits and duration of emergency overloads are:

Current overload, %	20	30	40	50	60
Permissible duration, min	60	45	32	18	5

64. Maintenance of the Buchholz Relay

Any fault in a transformer is generally accompanied by the evolution of gas. Therefore, each transformer is equipped with a gas-sensing Buchholz relay which has alarm and tripping contacts. If the Buchholz relay is to operate efficiently, the transformer should be set up so that its tank cover has a rising slope of at least 1 to 1.5% of the transformer height towards the relay. The oil piping from the transformer to the conservator should have a rising slope of at least 2 to 4%. A warning signal will be given when air finds its way into the transformer, when the oil level slowly falls due to low temperature or oil leakage, and also when minor faults accompanied by the evolution of small amounts of gas occur. The Buchholz relay disconnects the transformer from the line when an internal fault occurs accompanied with violent gassing. False alarm may be raised when a

through short circuit causes the oil to rush through the Buchholz relay and also when the control wiring at the relay is faulty due to attack by the oil. To protect the wiring, it should be provided with oil-resistant insulation.

An examination of the gas from the Buchholz relay can give attending personnel an idea of the nature of the fault in the transformer and the cause of the operation of the relay.

If the gas in the relay is without colour and odour, and will not burn, air is present in the transformer. If the gas burns, an internal fault has occurred in the transformer which must be immediately switched out for repair. The nature of the fault in a transformer can also be identified by the colour of the gas in the relay (Table 22).

Table 22

Transformer Faults as Identified by Colour of Gas

Colour of gas	Source of fault
White-grey	Paper or electric-grade cardboard
Yellow	Wooden parts
Black	Oil

To ignite the gas for a test, the flame should be brought sideways and slightly above the test cock outlet. To avoid an explosion, the flame should never be brought to the uncovered openings in the conservator and transformer.

Should the Buchholz relay give an alarm and a standby transformer be available, the load is transferred to the latter, whereupon the faulty transformer is examined to determine the cause of operation of the Buchholz relay.

When non-combustible gases are periodically evolved from the oil in a transformer, they are analyzed for hydrogen and methane. If their content gradually increases, the transformer should be switched out for repair, since this is an indication that the oil is being cracked by arcing. If the oil level drops due to decreasing temperature, some oil should be added into the transformer. Since fresh oil gives

off bubbles of air, it is usual to defer connecting the relay tripping contacts for some time in order to prevent false tripping. If the Buchholz relay has operated due to a cause other than ingress of air into the transformer, the oil should be tested for flash point.

When the Buchholz relay has disconnected the transformer from the line due to an internal fault, the transformer may only be switched back after the windings and core assembly have been inspected and tested.

65. Transformer Repair and Routine Tests

Routine repairs to power transformers are carried out, without removing the core and with the transformer disconnected from the line, in accordance with the conditions of service and in conformity with local regulations, but at least once a year.

Routine repair consists in cleaning the bushings and cover; inspecting all the contact joints, the conservator, and the gas vent pipe; testing the Buchholz relay, etc., which usually takes 6 to 8 hours to complete.

Overhauls of power transformers (with the core lifted out) are carried out after the first six years of service. Subsequent overhauls are scheduled as dictated by the measurement data and inspection results.

Overhauls are performed with the core lifted out and also include an internal inspection of the transformer, i.e. of the magnetic circuit, all coupling bolts, windings, contact joints, and insulation; cleaning of the tank and conservator, replacement of all gaskets, and all standard routine tests. The time required for an overhaul of a transformer is one to ten days, depending upon its size.

A transformer under overhaul or a new transformer being installed is tested in conformity with the pertinent codes and regulations. Between overhauls, routine tests are performed at the intervals specified in local regulations.

Transformers are tested for winding-insulation resistance, loss tangent, and absorption factor. Should the test results be indicative of winding humidification, the transformer should be dried out. The insulation of the accessible coupling bolts and yoke bars is tested by applying an AC voltage

of 1 kV for 1 minute. A breakdown of the insulation on these components may have grave consequences in the course of operation, since it leads to a shorting in the magnetic circuit and deterioration of the steel parts.

By measuring the winding resistance of a transformer with the tap changer switch set, in succession, to each of its positions, loose contact joints and breaks can be detected in the windings, and the winding terminals can be checked for proper connection to the switch. The same results can be achieved by measuring the transformation ratio of a transformer for all its taps. In passing from tap to tap, the winding resistance and transformation ratio must change by the same amount every time.

Turn-to-turn short circuits in the windings and faults in the magnetic circuit can be detected by measuring the no-load current of a transformer which rises if the said troubles occur.

With a newly connected transformer, a check on the phase-displacement group and paralleling are obligatory operations.

Oil samples taken from a transformer and its oil-filled bushings must invariably be tested as specified in Subsection 62. The condition of the bushings is determined by measuring the loss tangent.

While under routine repair, transformers are tested in accordance with local regulations.

Questions

1. What is the purpose of power transformer inspection, and at what intervals is it carried out?
2. What are the condition and quality of transformer oil judged by?
3. What overloads can be permissibly carried by power transformers?
4. What do you know about transformer protective relays of the Buchholz type?
5. What operations are carried out in the course of a power transformer routine repair and an overhaul?

CHAPTER 14

Operation and Maintenance of Alternators

66. General

Responsibilities of electrical duty personnel in supervision of running alternators (synchronous generators). Constant watch on and care of a running generator as a whole and its various parts is entrusted to the turbine-department operator. He should listen to the generator, check the temperature of its bearings and the cooling air, keep watch on the brushgear, and keep the unit clean. He should immediately inform electrical duty personnel of any abnormal or faulty operation detected in the generator.

The electrical duty personnel keep continuous watch on operation of the generator, check its operating conditions by the instruments on the control board, check regularly the insulation of the stator windings, rotor windings, excitation circuit, and bearings. The attendant on duty maintains the generator under specified active and reactive load and preset terminal voltage.

The operation of the generator is controlled from the main control board (Fig. 180). The control board attendant records, at hourly intervals, the readings of the instruments monitoring the generator performance. He sees that all parameters are within their permissible limits and takes measures to eliminate deviations, if any, from normal level. The control board attendant also keeps watch on the symmetry of the stator currents which must not vary considerably from phase to phase.

The attendant measures, once a shift, the insulation resistance of the excitation circuit with a voltmeter. This is accomplished by measuring the voltages V_1 and V_2 between each rotor slip ring and the generator shaft, and the voltage V between the slip rings. The insulation resistance

r_{ins} is calculated from the formula

$$r_{ins} = r_v \left(\frac{V}{V_1 + V_2} \right) 10^{-6} \text{ MΩ}.$$

where r_v is the internal resistance of the voltmeter (anywhere between 50 000 and 100 000 Ω).

The results are entered in a log book. For a running machine the insulation resistance should be at least 0.5 MΩ.

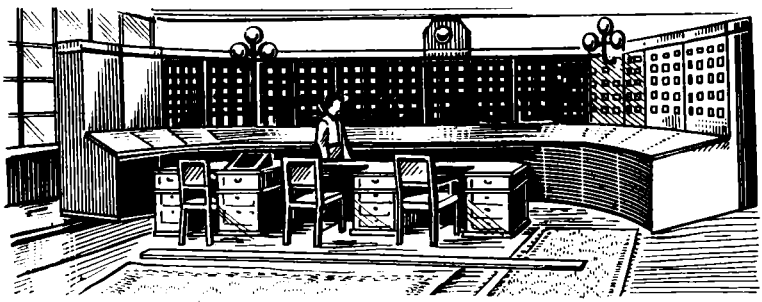


Fig. 180. Main control board. General view

Otherwise, measures should be taken to restore insulation resistance by blowing carbon dust off the brushgear and cleaning the latter. If the insulation resistance cannot be restored with the unit running, this must be done in the course of repair.

The duty personnel keep constant watch on the condition of the stator winding insulation. The stator winding is tested for insulation resistance with a 1 000 to 2 500-V megohmmeter during shutdowns. No particular value is specified by standards. A good practice, however, is to compare the test results with those of the previous test. When the insulation resistance sharply decreases (3 to 5 times), the cause should be identified and measures taken to eliminate it.

The insulating pads under the turbogenerator bearing pedestals should be periodically examined. In a running generator, an alternating EMF is induced along the rotor shaft, giving rise to currents circulating through the bearings of the set (Fig. 181). These currents may damage the

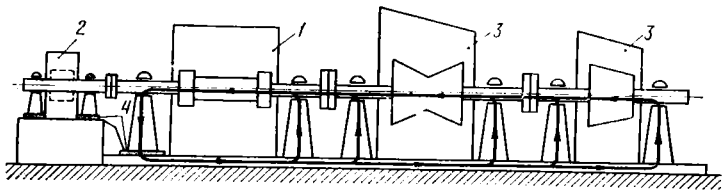


Fig. 181. Path of bearing currents in turbogenerator
1—generator; *2*—exciter; *3*—turbine; *4*—insulating pads

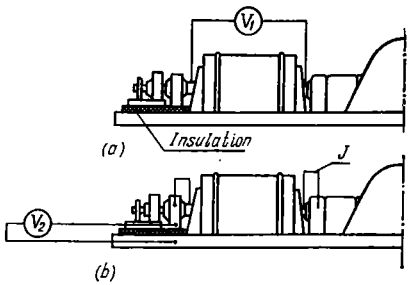


Fig. 182. Measuring of bearing-insulation resistance during operation of turbogenerator
(*a*) measurement of voltage across shaft ends; (*b*) measurement of voltage between insulated support of bearing and bedplate; *J*—jumper to shunt oil film

shaft journals and the bearing liners. To prevent this, the turbogenerator bearing at the exciter end and the bearing of the exciter are insulated from the machine bedplate by insulating pads. In addition, two adjacent flanges on each oil line are insulated from one another.

The resistance of the bearing insulation, with the turbogenerator running, is tested as diagrammed in Fig. 182. When measurements are taken with the voltmeter V_2, the resistance of the oil film in the bearings must be shunted. If the insulation is good, the voltmeters V_1 and V_2 will give identical readings. A difference in readings in excess of 10% indicates that the insulation has deteriorated, and the voltmeter V_2 will read less than the voltmeter V_1.

The responsibilities of the electrical duty personnel in-

clude maintaining the station's schedule of active load and voltage or reactive load.

The daily active and reactive load schedule determines how much power a station should generate every hour, which is the *daily target.* The schedule comes from the chief operator of the power system and should be followed without fail. Guided by this schedule, the station's engineer on duty divides the load between the running generators continuously supervised by the electrical duty personnel.

The required active load is maintained by controlling the rate of steam flow into the steam turbine or the rate of water flow into the water turbine and watching the wattmeters to see load variations.

The prescribed voltage or reactive load is maintained by varying the field current of one or several generators. A larger field current corresponds to a larger stator current, a greater reactive load on the generator, and a higher voltage at its terminals and vice versa.

The voltage of generators rated at 3 000 kW and higher is controlled automatically by voltage regulators which are adjusted to compensate for a voltage drop due to an emergency by raising the field current to its maximum value. In addition, the excitation circuit incorporates a field rheostat for manual voltage adjustments.

The electrical duty personnel who check the operating conditions of the generator by the instruments must also make a round of the generator once a shift in order to:

listen to the running generator for any deviation from normal operation;

check the temperature rise of the bearings, stator, and exciter;

inspect the brushgear of the rotor slip rings and exciter; sparking, if any, is eliminated by adjusting the spring pressure, cleaning the brushes, commutator, and slip rings;

detect any heating in current-conducting parts with the aid of temperature indicators or by changes in the colour of strips of thermosensitive film;

carefully inspect the entire relay equipment and the alarm circuits for any failure to operate properly. The above procedure of inspection should also be followed off schedule after each external short circuit.

67. Abnormal Operating Conditions and Troubles of Generators

Discussed below are the abnormal conditions to be eliminated in operation.

Overloads. Any overload is detrimental to the stator and rotor windings because the temperature rise accelerates the process of insulation ageing. The copper of the coils tends to elongate, thus deforming the insulation, which may lead to turn-to-turn shorts in the windings. Because of this, generators should not be loaded for considerable periods of time with currents greater than is permissible at a given temperature of the cooling air or gas.

Short-time overloads of generators are permissible under emergency conditions in the power system, as specified in relevant operating rules.

Earth faults. Generator operation with an earth fault existing in the generator-voltage circuit may be tolerated for no longer than two hours. Should an earth fault occur in the stator winding of a generator, the generator is turned off by the protective gear. When an earth fault appears in the rotor winding of a generator, the duty personnel should identify and locate the fault. In the case of a sustained and solid earth fault, the protection of the excitation circuit against double earth faults should be switched in. A generator having an earth fault in its rotor winding should be taken off the line for repair at the first opportunity.

Unbalanced loads. Turbogenerators are designed to carry full load continuously with the phases loaded equally to within 10% of the rated stator current. For water-wheel generators this tolerance is 20%. In both cases the current in any one phase should not exceed its rated value. Whenever load unbalance grows impermissibly high, measures should be taken to reduce it. If this cannot be done within 2 minutes, the load should be disconnected from the generator, and the latter switched off the line, because the negative-sequence fluxes set up under unbalanced load induce double-frequency currents in the field winding and the rotor core (Fig. 183). They give rise to additional losses both in the metal parts of the rotor and in the winding and cause dangerous local overheating.

Asynchronous running condition. Operation in the asynchronous running condition which occurs when the excitation disappears during operation may be tolerated for 30 minutes. The load which the generator may be allowed to carry in such cases is determined by test.

Disconnection by protective gear. If the generator has been switched off the line by its protective gear because of an internal fault, the stator and rotor windings must be

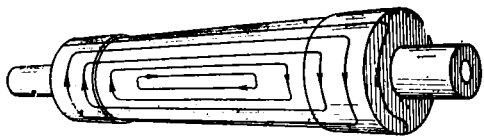


Fig. 183. Paths of currents induced in turbogenerator rotor by negative-sequence magnetic field

tested for insulation resistance, the generator inspected, and its associated equipment and cables checked. If the generator has been switched out by an overcurrent relay due to a short circuit in the system or on the station buses, it may be put in operation.

Appearance of the MACHINE IN DANGER signal. Should an emergency occur in the generator or the turbine (fire, smoke, heavy vibration, etc.), calling for immediate disconnection of the generator, the operator on duty should strike the emergency automatic trip of the turbine and relay the MACHINE IN DANGER signal to the control board. On receiving the signal, the electrical duty personnel should make sure that the generator is relieved of its active load, disconnect it from the line, and switch off the excitation current.

Sparking. All measures should be taken to eliminate heavy sparking on the exciter commutator or the rotor slip rings. If necessary, the excitation current should be decreased by lowering the active and the reactive load to a point

where sparking ceases. If the sparking still persists, it is necessary to change over to a standby source of excitation current.

A generator in which a turn-to-turn short circuit has developed in the rotor winding should be immediately taken off the line.

Motor action of a generator does not present a danger to it for any interval of time, unless the associated turbine imposes any limitations.

68. Generator Routine Tests

Generator routine tests include:

insulation resistance tests on the stator winding with a 1 000 to 2 500-V megohmmeter, and on the rotor winding and all the excitation circuits with a 500-V megohmmeter;

measurement of DC resistance of all the windings; the measurement data should not vary from those obtained in the previous tests by more than 2%;

insulation tests with the AC test voltage applied for 1 minute between each phase of the stator and the frame, and the other two phases returned to earth. The test voltage should be 1.5 to 1.7 times the rated line voltage. In generators with extended overhaul periods the stator winding should be tested for insulation resistance by applying a voltage 1.7 times the rated line voltage;

testing of stator-winding insulation with a rectified voltage and concurrent measurement of leakage current. The test voltage applied for 1 minute should be 2 to 2.5 times the rated line voltage;

measurement of DC resistance of the field-discharge resistor. The resistance should not differ from the rated value by more than 10%;

testing of field-discharge resistor insulation with a commercial-frequency voltage of 2 kV for 1 minute;

testing of exciter armature for insulation resistance to the frame and to the wire binding with 1 000 V AC for 1 minute;

testing of generator bearings for insulation resistance

to bedplate with oil lines joined. The insulation resistance should be at least 1 MΩ;

measurement of vibration. The vibration of bearings in synchronous generators and synchronous condensers should not exceed 0.18 mm at 62.5 to 187.5 rpm (rated), 0.12 mm at 214 to 375 rpm (rated), 0.10 mm at 500 to 1 000 rpm (rated), 0.07 mm at 1 500 rpm (rated), and 0.05 mm at 3 000 rpm (rated);

measurement of air gaps between stator and rotor. Under the USSR Electric Installation Code, the air gaps across the diameter shall not differ by more than 20% of the average value in water-wheel generators, and by more than 10% of the average in turbogenerators and synchronous condensers;

measurement of a three-phase short-circuit characteristic. With synchronous condensers, this test is obligatory only when they have a starting motor. The difference between the short-circuit characteristic so obtained and that given by the manufacturer should be within the limits of measurement accuracy;

testing of the bearing insulation relative to the bedplate when the set is in operation. The voltage across the rotor shaft should equal the voltage between the bearing and the bedplate, with the oil films of the bearings shorted;

testing of generator synchronizing circuits with sync voltage if work has been done on them.

69. Generator Repair

All generators are regularly subjected to routine repairs and overhauls.

Routine repair includes inspection and cleaning of:

the stator-winding end coils and generator leads;

the gas coolers, chambers, and filters of the cooling system;

the exciter and the apparatus in the excitation circuit;

the associated switchgear.

In accordance with the manufacturer's instructions, a typical overhaul of a generator covers:

the stator and rotor;

the exciter;

the excitation system;
the shaft and thrust bearings;
the gas coolers and cooling-system filters;
the associated switchgear and auxiliary equipment.

Generators are overhauled after one year's service and thereafter at two or three years' intervals. Water-wheel generators are overhauled every four years.

The rotor of a turbogenerator is pulled out of the stator for inspection and repair after one year's service and whenever necessary afterwards, but at least every five years.

The rotor of a water-wheel generator is pulled out as the need arises.

Drying-out of generators. After an overhaul, generators are put into operation without drying out. Newly installed generators may have to be dried out, in compliance with relevant instructions, depending on how moist their insulation is. Generators may be dried out either prior to or during installation by one of the following methods:

by heating the stator core with a magnetic field set up by a special field winding (or, sometimes, by the rotor shaft);
by heating the winding with direct current or hot-air blowers.

Both methods are employed when the generator is at a standstill.

Generators may also be dried out under load.

A generator is considered dried out when, at a steady temperature, the insulation resistance of the stator winding and the R_{60}/R_{15} ratio remain constant for three to five hours after an initial temperature rise.

The rotor winding can be dried out:
with direct current from an independent source;
using hot-air blowers;
concurrently with the stator, the rotor being inserted.

A rotor winding is considered dried out when its insulation resistance, after an increase, remains constant at not less than 0.5 MΩ for at least three hours.

Questions

1. What are the responsibilities of electrical duty personnel in supervision of running generators?

2. What path do the bearing currents take in a turbogenerator?
3. What abnormal operating conditions and troubles of generators do you know?
4. What measurements and tests are included in generator routine tests?
5. What operations are included in a generator routine repair and an overhaul?

CHAPTER 15

Maintenance of Overhead Lines

70. General

Every power system has, as a rule, a ramified network of overhead lines which cover a large area. For convenience in control, operation, and maintenance, the entire network is divided into districts, each including a number of substations and lines.

Each district is staffed with attending personnel and provided with workshops, transport facilities, etc. The lines in each district are subdivided into line sections for which patrol posts and line-service stations are responsible.

A patrol post is the primary link in the line-maintenance set-up. Such a post is staffed with two patrolmen residing at their post, who make periodic inspections of the lines in their charge.

The line-service stations carry out routine maintenance work on the line sections. These stations employ several repair crews, each consisting of 4 or 5 linemen, and have their own trucks, materials storehouse, and a workshop. A line-service station is headed by a senior lineman.

The patrol posts and line-service stations within a district have telephone communication with one another and with their district office.

The main objectives of overhead line maintenance are:

to perform regular inspections of and routine tests on the lines in order to detect possible faults in good time;

to carry out the necessary repairs.

71. Inspection of Overhead Lines

Regular inspections (patrolling). Regular inspections are conducted by patrolmen with the aim to check the condition of the lines and to detect possible faults.

Depending on the local conditions and the importance of the lines, the inspection intervals are fixed by the chief engineer of a given power system. For the lines of industrial enterprises the inspection intervals are fixed by their chief power engineers. In both cases inspections should be made at least every six months.

Listed below are the main types of fault in power transmission lines to be detected by patrolmen and remedied afterwards.

Metal supports: supports tilted across or along the line, deformed cross-arms and earth-wire supports, settled or bulging soil around support foundations, yielding of foundations, cracks and breaks in foundations above ground level, missing nuts on the anchor bolts, rust and cracks (especially at joints and gussets), warped or buckled elements in the supports, cracked welded joints, and poor riveted and bolted joints.

Wood-pole supports: supports tilted across or along the line, misaligned support parts, (cross-arms, etc.), earth poorly banked up around support poles, missing bolts and nuts, short thread on bolts, broken or loose wire bindings, missing keys and wedges, rotted, burned or split support parts.

Conductors and earth wires: foreign objects on conductors or earth wires, broken cable conductors, excessive tension or sag, improper conductor clearances to earth, crossed lines, and other obstructions, corrosion of conductors and earth wires, vibration, ice formation.

Line accessories and joints: defective clamps, sleeves, and connectors, missing bolts, washers, or cotter pins, loose nuts, signs of overheating on clamps or connectors, conductors slipping in their clamps, loose earth wires, faulty cross loops at anchor supports (loop too near to support structure or bent), poor conductor-to-insulator attachment.

Insulators: broken porcelain, burned and fused spots on glazed surface, traces of fusion on the insulator and fittings, dirty insulators, out-of-the-vertical suspension strings, missing locks or cotter pins in suspension strings, rods slipping out of insulator caps, bent pins and rods, rusty fittings, noticeable corona.

Earthing equipment: damaged or broken downward earth

wires on supports at ground level, missing wire fixing staples on supports, and missing joint sleeves at the tops.

Lightning arresters: burned or damaged arcing horns and rings, defective breakdown indicators, fused electrodes in the external spark gaps, and wrong gap settings.

In addition, the condition of the right-of-way should be checked during inspection. The right-of-way boundaries are the lines parallel to the line and separated from its outer conductors by the following distance:

Voltage, kV	1-20	35	110
Distance, m	10	15	20

The right-of-way should be free of hay stacks, peat and timber piles; trees that have become a danger to the line conductors must be felled.

Patrolling is necessary when trees and shrubs are being planted, earth moved, levelled, or blasted, civil engineering work done, cable and pipe lines laid, electric power and communication lines erected, roads constructed, or unloading areas cleared, etc., within or near the right-of-way. The roads, road bridges, and footpath bridges within the right-of-way should also be inspected. All faults detected by the patrolman should be entered in a Patrol Report tear-off notebook.

Back from a round of the line, the patrolman reports to his superior and enters the notes from his Patrol Report in a special log book kept at the patrol post or at the line-service station. The original of the Patrol Report is sent to the district office, and the carbon copy is left in the patrolman's notebook. Follow-up entries are made in the log book after the faults detected by the patrolman have been remedied.

Minor defects on the lower parts of supports, such as loose bolted joints and wire bindings, unfastened warning signs, etc., are fixed by patrolmen. Yet they should by no means climb the supports, for even if the line is dead, it may be energized at any instant.

While on an inspection round, patrolmen should never walk under the conductors, but a short distance away from them. When a broken conductor is discovered, the patrolman should post guards at least 8 to 10 m of the broken con-

ductor, warning the guards that closer approach is dangerous to life. If there is no one to put on watch, the patrolman should remove the warning notices from the nearest two or three supports, put them up near the broken conductor, inform the district office of the break, return to the point of break, and wait for an emergency crew to arrive.

Off-schedule inspections. Such inspections are made in the event of ice formation, thick fog (in sections subject to heavy contamination), at the time of ice drift and river floods, after forest and steppe fires, etc. Their purpose is to detect possible damage and breakage on the line and to carry out the necessary repairs.

Off-schedule inspections should also be made after severe frosts, as the sharp drop in temperature may result in the breaking of separate strands in a conductor, porcelain insulators, etc., due to increased tension.

Night inspections for corona, surface leakage, and overheated conductor joints clearly visible in the dark also come under this heading. Special inspections are conducted by appointed crews of linemen directed by engineers.

Inspections should also follow each automatic trip-out of a line, irrespective of whether it has been reclosed or not, to locate and identify the fault due to an emergency and estimate the amount of repair involved. These inspections are conducted by emergency crews. In the most serious cases, and on especially vital lines aircraft may be used.

Support-head inspections. Many faults on the line, including conductors damaged by clamps, fine cracks in the insulator porcelain, and defects in line accessories can be discovered only by climbing the supports, which is known as support-head inspection. Such inspections are normally conducted, with the approval or by order of the system's engineer in charge, at least every six years.

This inspection requires that the line be dead. In order not to interrupt power supply to the users for long, this work is performed by a large number of line-service crews under an experienced foreman, technician, or engineer.

Support-head inspections also include minor line repairs, including replacement of defective insulators, etc.

Check inspections. These inspections are conducted by engineering personnel as a check on the condition of the

right-of-way and the line and the efficiency of the patrolmen. The results are summed up in a check inspection report which lists all the defects revealed, estimates the scope of the necessary repairs, and fixes the date by which the work must be completed. Check inspections should be conducted at least once a year.

72. Routine Tests on Overhead Lines

In addition to inspections, overhead lines are regularly subjected to routine tests and checks.

Parts of wood-pole supports are tested for decay due to fungi at least every three years, and also prior to replacement of rejected wooden members.

The condition of antirust coating on metal supports and cross-arms is checked every three years. The underground parts of metal supports and guy-wire anchors are checked every six years, with the soil ripped up at random.

The concrete of reinforced-concrete supports and stubs is checked after three years in service and, subsequently, every six years.

Suspension insulators are tested for electric strength during the first year in service and, subsequently, depending on the percentage of insulators rejected during the preceding period, but at least every six years.

The electric strength of glass and pin-type insulators is not measured; their condition is assessed visually, while inspecting the line. The resistance of conductor joints on lines rated at 35 kV and over is measured during the first year in service and, subsequently, every six years. The resistance of welded conductor joints is measured only once—when they are brought into use or during the first year in service. The resistance of joints on steel-cored aluminium conductors in which the steel cores and aluminium wires have been compressed separately does not have to be measured.

The resistance of bolted conductor joints is measured every three years and, moreover, all bolted joints are inspected at least every six years. The resistance of line-support and earth-wire earthing connections is measured at least every six years. For earthing connections subject to severe cor-

rosion the test intervals are reduced. Besides, the resistance of earthing connections is measured after they have been rearranged or overhauled.

Conductor clearances to earth and various adjacent and crossing objects (on lines with jointly suspended conductors and for parallel conductors in a span), tension in support guys, bolted joints and bandings on supports are checked as the need arises. All faults revealed by inspections, routine tests, and measurements are entered in a failure repair sheet to be remedied during the next overhaul.

Faults of emergency nature should be remedied at once. In accordance with the Station and Line Operating Rules, routine tests and measurements and also support-head inspections should be conducted at the same time where possible.

Decay testing of wood-pole supports. Pole decay is due to fungi whose growth is supported by the varying moisture content of the atmosphere and the upper layers of soil.

To protect wood poles from decay, they are impregnated with preservatives. This preservation considerably extends the service life of wood-pole supports, makes them more reliable in service, and very significantly reduces repair work and, consequently, line outage time.

The most efficient method is the impregnation of seasoned poles in a special plant. As a matter of record, the most important lines which operate at 20 kV or higher and transmit large amounts of power use, if at all, only wood-pole supports treated as described above. What is called local or brush treatment is less effective.

A decay test consists of a visual inspection, hammering, and measurement of the depth of decay.

In a visual inspection the poles are examined for rotten spots and areas, and cracks.

Hammering provides a check on the condition of the core of the wood. A clear ring is an indication of healthy wood, while a dull sound is a sign of decay. Hammering is best done with a 0.4-kg hammer in dry unfrosty weather, because moist or frozen wood distorts the sound.

If inspection and hammering reveal decay, its depth is measured with a probe or an ordinary 10 to 12-mm drill at the most critical sections of each part and at the points

of greatest decay. In vertical or inclined parts, such as stub poles, vertical braces, X-braces, rests, the depth of decay should be measured at three points spaced at 120° round the circumference. Horizontal parts, such as cross-arms, lateral braces, cross-bars, should be measured at two points round their circumference. The probe should be forced into the wood by hand. Neither a hammer nor any other tool may be used for the purpose. When an ordinary drill is used, the depth of decay is measured between the points where rotten borings start and stop to come out.

All holes made during a decay test should be treated with antiseptic paste and plugged with impregnated wooden dowels.

The results of the decay test are entered in a check-off list.

Checking metal supports for corrosion. Rust on metal supports is most likely to be formed at the joints and on the horizontal members due to accumulation of dust and moisture. Underground parts are also liable to corrosion.

The extent of damage to the metal by corrosion is determined by measuring the remaining cross section of the part. For this, the metal should be cleaned of rust.

Special attention should be paid to the condition of paintwork on the metal parts above the suspension insulator strings, as rust washed down from them by dripping water tends to deposit on the porcelain insulation, thus impairing its insulating capacity.

Metal supports near sea shores, large electric power stations, chemical plants, and steel works are subject to heavier corrosion than supports in other districts and therefore require more frequent and closer inspection.

Conductor vibration control. The vibration of overhead conductors is a periodic oscillatory motion of conductors caused by wind. Tests have shown that the frequency of vibration depends upon conductor diameter and wind velocity. The frequency varies with wind velocity from 10 to 50 Hz, the resulting waves being from one to 10 or even 20 m in length and several centimetres in amplitude.

Vibration leads to fatigue of the conductor metal, breakage of its strands, and the consequent failure of the conductor as a whole, usually at clamps. Vibration also causes

damage to the insulators, cotter pins, line accessories and, in some cases, line supports.

Regular inspection and timely repair play a major part in preventing damage to conductors by vibration. Overhead lines can be protected against conductor vibration as follows:

by reducing the resultant mechanical stresses due to vibration to a safe value below the fatigue limit of a given conductor material;

by checking or damping vibration to safe limits by means of vibration suppressors (dampers).

Ice control. Ice will form on conductors over a small temperature range close to 0°C, due to sleet, rime, or glazed frost, when a thaw is followed by a drop in temperature. In most cases the temperature at which ice will form will be between 0° and —3°C and may be sometimes as low as —6°C. Intensive ice formation may result in extreme loads which may break conductors.

To be ready for ice control, it is good practice in areas subject to heavy ice formation to keep watch on the weather conditions under which ice will form.

Ice formation on conductors can be controlled by heating the conductors with load or short-circuit currents (ice melting), and by mechanical cleaning.

When conductors (or earth wires) are heated with a current, the current density is raised to a point where enough heat is developed in the conductor to melt off the ice. This can be done as follows:

by transferring loads from other lines to the line in trouble;

by heating with short-circuit currents;

by connecting transformers in opposition.

Mechanically, ice from conductors and earth wires can be removed by knocking it off with long poles of bamboo or wood, or tubes of phenolic resin plastic, and also by working the ice off with a cord (e.g. of kapron or other similar material).

Measurement of overhead conductor clearances. Conductor clearances should be checked periodically as they may change under service conditions. Undue changes in conductor clearances are generally caused by conductors slipping in suspension clamps owing to unequal tension in adjacent spans

or elongation with time, tilted or displaced (after a repair) supports, change in length of a suspension string due to replacement by a different type or number of units, construction of new roads under or near the line, reconstruction of existing structures, electric power lines, earth embankments, and other engineering installations.

Line clearances may be measured with an optical instrument used in surveying (theodolite) or with some other special instrument adapted for work on live overhead lines.

Inspection of line insulators. During service on an overhead line, insulators are subject to mechanical and electric stresses which shorten their service life or cause damage.

Defective insulators are detected for timely replacement by means of an insulator grading stick or by high-voltage testing during a round of special or regular inspection. Defective ("zero-voltage") insulators should be replaced as soon as the line can be switched off.

Inspection of joints. Joints deteriorate in service with time to a point where they may lose some of their conductivity due to short circuits which cause considerable overheating and impair contact between the parts of a joint, and to corrosion on the contact surfaces which causes overheating and redistribution of current through the cross-sectional area of a joint and sometimes, as a consequence, burning-through of some of its elements.

Poor jointing, dissimilar metals in a joint, and improper type of connector for a given conductor bring about the failure of joints. Poor electric contact or low mechanical strength in a joint may lead to the overheating and breaking of a conductor.

Defective joints are detected for timely replacement and failure prevention during special inspections and also during periodic day and night patrolling. The absence of snow or ice on a joint when it is present on the conductor, or a connector glowing in the dark indicates poor contact in the joint.

Since the voltage drop across a joint is directly proportional to its resistance, the quality of the joint can be judged by the ratio V_j/V_c, where V_j is the voltage drop across the joint being checked and V_c is the voltage drop across a piece of conductor as long as the joint.

In addition, the conductivity of joints is regularly measured as part of preventive maintenance. Joints are tested:
with direct current on dead lines;
by using special testers to measure the voltage drop on live lines.

Inspection of conductors and earth wires. In service, conductors and earth wires are subjected to tensile stresses due to their pull, to compressive stresses in the clamps, and to bending stresses at the clamps. Their condition may also be affected by poor welded joints on individual strands, poor galvanizing, and inferior workmanship in stringing (kinks, crushed spots, torn and notched strands, ruptured galvanized coating, overtensioning, etc.).

As a result, some strands and a conductor as a whole may break, especially where it is secured in clamps on line supports, or somewhere in mid-span. Because of this, conductors must be regularly inspected at their clamps, particularly at suspension clamps where some of the strands may break as a result of fatigue due to vibration. This happens less often in tension clamps and joint sleeves.

Broken strands in a conductor are difficult to detect by visual inspection without taking it out of the clamp. Therefore conductors should periodically be taken at random out of their suspension clamps wherever local conditions require such inspections.

73. Line Repair

Overhead lines may be given either routine repair or overhauls. The aim of routine repair is to maintain the line and its auxiliary structures at the necessary level of serviceability. The aim of overhauls is to fully restore a damaged line and its auxiliary structures to their necessary strength. Overhead lines and their specific sections should be overhauled every three to six years.

Overhauls may be carried out on dead lines, on a line in which only the phase to be repaired in opened, or on live lines.

As a rule, repairs to overhead lines should be carried out so that all necessary operations are performed simultaneous-

ly, with the line outage time and the number of movements along the route reduced to a minimum.

It should be remembered that the Station and Line Operating Rules forbid making changes in the design of line elements and in the way of fixing the line supports in the soil unless it has been permitted by the chief engineer of the system involved. Also in conformity with the Operating Rules, lines with jointly suspended conductors should be repaired by their users according to an approved schedule. In the event of an emergency, the other party concerned (the owner of the line or conductors) should be informed of repairs in advance.

Organization of repair work. Repair work may be carried out: on dead lines which should be fully de-energized and earthed;

on a line in which only the phase to be repaired is opened;

on a live line.

Before any repair is commenced, the crew assigned to do the work should be briefed on the rules of work and safety. If the work is to be done on a live line, they should undergo training exercises in addition to briefing.

The actual repair work to be done on an overhead line is scheduled on the basis of the data obtained through inspections and routine tests, giving priority to troubles threatening normal operation of the line. Any fault fraught with an outage should be remedied on an emergency basis.

Scheduled line repairs include:

replacement of damaged or heavily decayed parts of wood-pole supports;

replacement of defective supports as a whole;

impregnation of wood-pole footings with preservatives;

painting of metal supports;

replacement of damaged insulator units and strings;

replacement of specific line accessories;

cutting-out and replacement of damaged conductor sections;

replacement of conductors and earth wires on some line sections;

sag adjustment on conductors and earth wires;

repair of earthing conductors run down the supports;

repair of lightning arresters.

For the most part, line repair is performed by the same methods as are used for initial installation. In some cases, however, in order not to interrupt the supply of power, repairs are carried out on live lines and by other methods than those used for installation.

74. Repair of Live Overhead Lines

Repair on a live overhead line may include:

inspection and repair of conductors, insulator strings, and line accessories (on 35- to 220-kV lines);

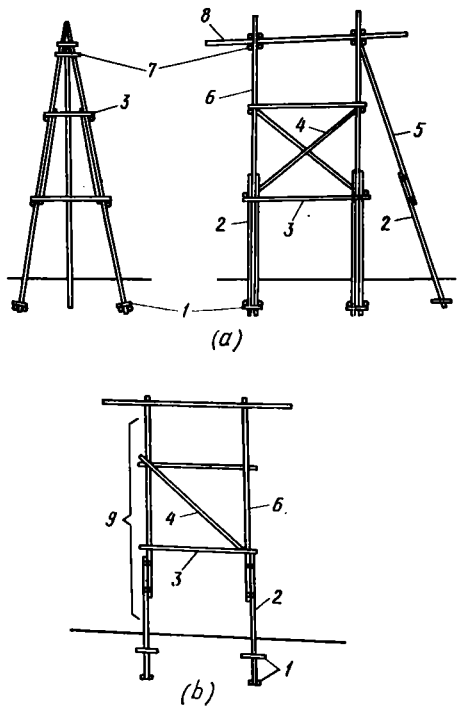


Fig. 184. Parts of wood-pole supports for 35- to 110-kV overhead electric power lines

(*a*) angle-suspension support; (*b*) tangent-suspension support; *1*—crib braces; *2*—stub pole; *3*—horizontal brace; *4*—angle brace; *5*—stay pole; *6*—leg pole; *7*—cross-bar; *8*—cross-arm; *9*—support leg

replacement of wood-pole support parts (Fig. 184), straightening of anchor and tangent-suspension supports, and complete replacement of tangent-suspension wood-pole supports (on 35- to 110-kV lines);

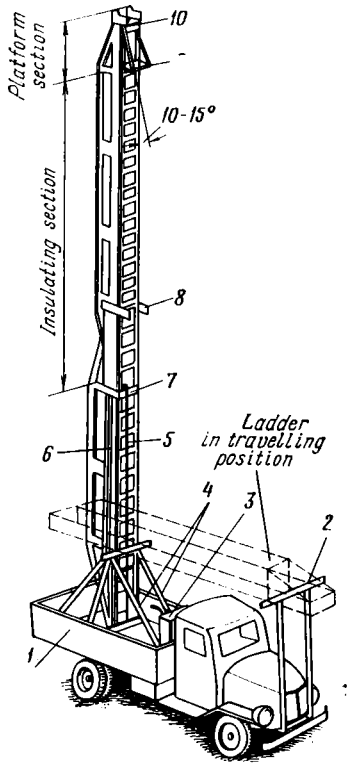


Fig. 185. Double-section insulated ladder

1—truck body; *2*—front support frame; *3*—raising-extending winch; *4*—ladder base; *5*—ladder extending wire rope; *6*—latch frame; *7*—middle bracing; *8*—upper bracing; *9*—metal platform; *10*—tool box

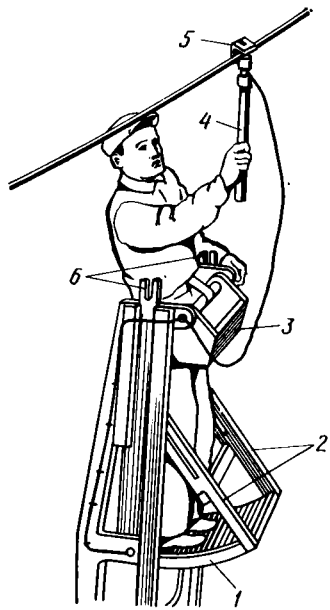


Fig. 186. Platform of insulated ladder provided with removable live-line clamp

1—metal platform; *2*—strain members; *3*—tool box; *4*—insulating stick; *5*—live-line clamp; *6*—extendable frame

installation and removal of protector tubes (on 35- to 110-kV lines).

Inspection or repair of a live line or phase calls for the use of insulating devices and tools enabling the lineman to touch the live elements of the line. These include insulated ladders, telescopic towers, insulated platforms, special sticks, clamps, etc.

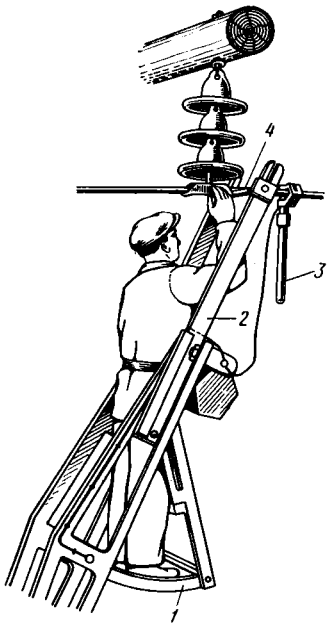


Fig. 187. Platform of insulated ladder fitted with extendable frame

1—platform; *2*—extendable frame; *3*—stick with live-line clamp; *4*—roller

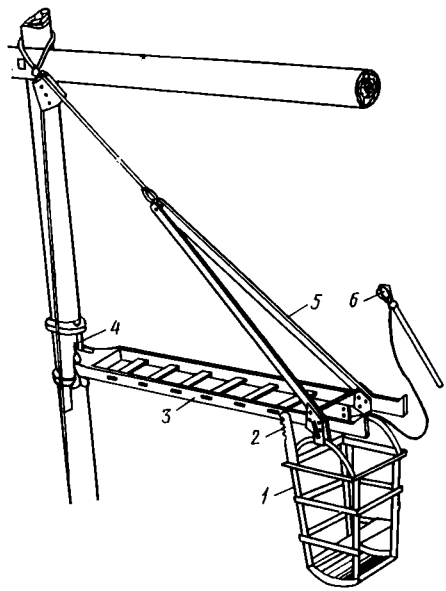


Fig. 188. Swivel insulated platform shaped as cradle (lineman works standing)

1—cradle; *2*—cradle latch arm; *3*—main frame; *4*—swivel attachment; *5*—strain rods; *6*—live-line clamp

An insulated ladder (Fig. 185) consists of a top platform on which the lineman can stand, an insulating section used to isolate him from earth, a base on which the ladder proper is mounted, and a winch to raise and extend the ladder. The top platform is furnished with a removable liveline clamp and an extendable frame. Fig. 186 illustrates how the metal platform of the insulated ladder is electrically connected to the live-line clamp fitted on a special stick 0.7 to 0.8 m long.

The platform is automatically retracted when the ladder is lowered and swings out when the upper section is extended.

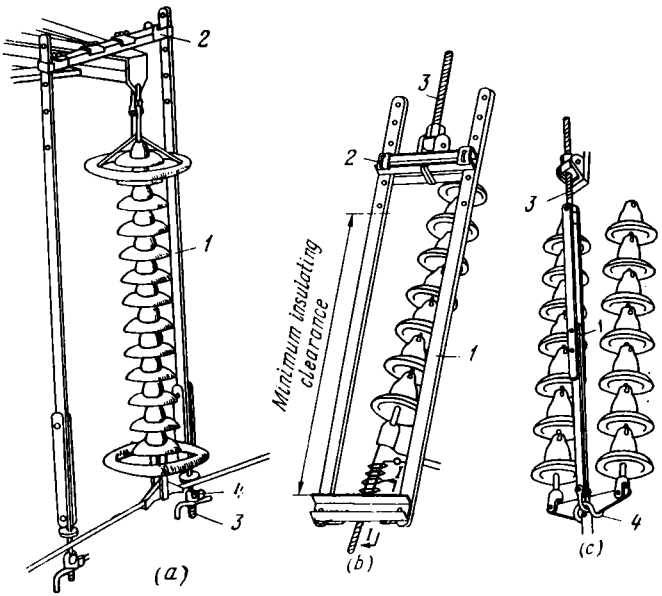


Fig. 189. Insulating sticks

(*a*) arranged on tangent-suspension support; (*b*) for replacing single tension strings; (*c*) for replacing double tension strings; *1*—strain bar; *2*—upper cross member; *3*—clamping screw; *4*—engaging link

The extendable frame built into the platform (Fig. 187) terminates in a metal roller free to rotate on a shaft.

The extendable frame is used where:

the distance between the top platform and the live-line element should be 1.75 to 2 m;

a conductor up to 200 kg in weight needs to be put on the ladder.

An insulated platform is used when a lineman working close to a support should be able to touch live parts.

It consists of a cradle or seat (Fig. 188) equipped with a removable live-line clamp, an insulating support assembly (main frame and strain rods), and a swivel assembly.

Insulating sticks are employed when a string of insulators has to be replaced on overhead lines operating at 110 kV and over.

The insulating sticks shown in Fig. 189*a* are used to replace suspension insulator strings and to take conductors out of their clamps for inspection.

Tension insulator strings are replaced using insulating sticks of a different type (Fig. 189*b* and *c*).

In doing work on a live line, particular care should be exercised, and safety rules strictly observed. Operations of this kind may be entrusted only to specially trained personnel who have been examined on their knowledge of safety rules and specific job requirements.

Questions

1. What do you know about the principles of overhead line maintenance?
2. What is the purpose of regular, emergency, support-head, and check inspections of overhead lines?
3. What is the purpose of, and the intervals between, tests on overhead lines?
4. What causes ice formations on the conductors and earth wires of overhead lines, and why it should be controlled?
5. What principles are followed in doing repair work?
6. What is characteristic of repairs to live overhead lines?

CHAPTER 16

Accident Prevention in Operation and Maintenance of Power System Equipment

75. General

Making station, substation, and line equipment safe in handling is an important objective of its operation and maintenance. Strict rules for doing work on operating electrical installations and organizational and technical measures that must be taken to ensure safety are laid down in Safety Regulations.

Electrical installations are considered to be operating if they are live fully or in part, or if the voltage may be applied to them at any instant. Work on operating electrical installations is permitted only for persons over 17 years of age who have been trained in the rules of safety in operation and maintenance of electrical equipment, successfully passed an examination before a qualification board, and been issued a safety qualification certificate. In the USSR five safety rating groups exist. Persons of Group 1 safety rating should never be allowed to enter an operating installation alone. Higher safety ratings are given to persons with firm knowledge of safety rules, skilled in safe performance of their jobs in an operating installation, familiar with the circuitry and equipment of the sections they are in charge of, and able to render first aid to a victim of electric shock. Persons working on operating electrical equipment should be given medical checkups every two years.

To prevent unauthorized persons from entering operating installations, all rooms containing current-carrying parts must be locked, with warning notices posted at the entrance.

In switchgear installations the equipment and buses are railed in or arranged at such a height that they cannot be touched by accident.

Those who are doing repair work are most exposed to danger, as they are very near to the equipment, within the permanent guards. To ensure safety in performing such jobs, safety regulations provide for special technical and organizational measures.

76. Technical and Organizational Measures for Ensuring Safety

Among the *technical measures* taken to ensure safety at work are de-energizing of equipment, placing of temporary guards and warning notices, no-voltage tests, and attachment of temporary safety-earthing sets.

De-energizing of equipment. All current-carrying parts on which work is to be done should be disconnected from the line. This also applies to all current-carrying parts which personnel may accidentally touch or approach closer than the following distances:

0.7 m for parts at rated voltages up to 15 kV inclusive;
1 m for rated voltages from over 15 to 35 kV inclusive;
1.5 m for rated voltages from over 35 to 110 kV inclusive;
2 m for 154 kV;
3 m for 220 kV;
5 m for 400 kV.

This should be done so that disconnected equipment is isolated from live plant on all sides and a visible break provided on each side. No work shall be allowed on equipment cleared only by opening circuit breakers.

Once the equipment is de-energized, the supply of control current to circuit breakers must be interrupted and the operating mechanisms of isolators padlocked to prevent their reclosure.

Guards and warning notices. The DO NOT SWITCH—MEN AT WORK! notices should be hung on the operating mechanisms of all circuit breakers and isolators and on all control keys with which the voltage may be applied to the equipment where men work (Figs. 190 and 191).

In indoor substations the STOP—HIGH VOLTAGE! notices should be hung on the wire-netting or solid walls of the compartments or cells adjacent to and opposite the location where work is to be done. If these cells have no bar-

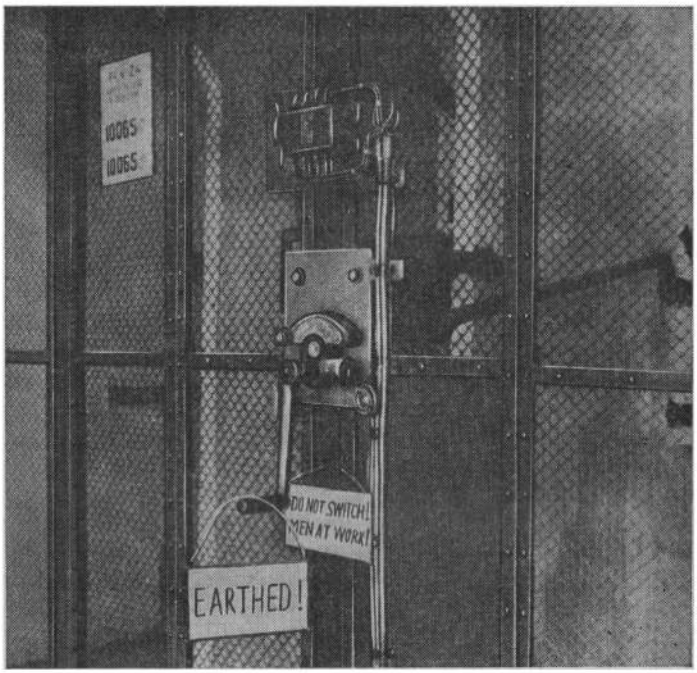


Fig. 190. 10-kV switchgear cell switched out for repair (isolator with ПЧ-50 operating mechanism)

riers, portable guards bearing the words STOP—HIGH VOLTAGE! should be put near them and at all points where maintenance personnel is not allowed to enter.

In outdoor substations the work location is fenced off with a rope from which a STOP—HIGH VOLTAGE! notice is hung. When work is done on top of a common structure, the work location is marked off by the STOP—HIGH VOLTAGE! notices to block the way to the adjacent live sections. On the ground, the DON'T CLIMB—DANGEROUS TO LIFE! notices must be attached to the structures next to the one used by personnel. On the structures which the crew is allowed to climb to reach the work location, the CLIMB HERE! notices should be hung.

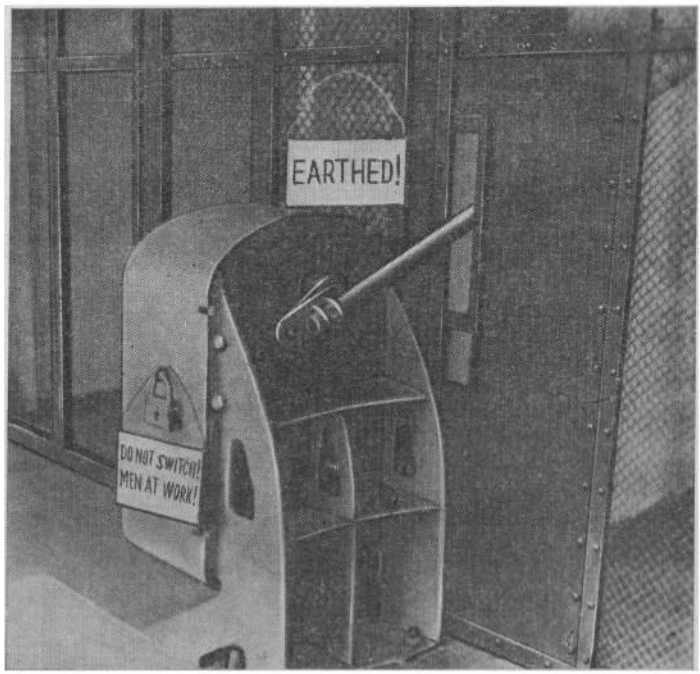


Fig. 191. 10-kV switchgear cell switched out for repair (isolator with motor-driven operating mechanism)

The WORK HERE! notices should be placed at the work location on completion of preparatory operations.

No-voltage test. That the disconnected equipment is dead is ascertained by duty personnel after the necessary warning signs and temporary barriers and guards have been put up and temporary safety-earthing sets have been connected to the grounding mat. Prior to a test, the voltage indicator (Fig. 192) used for the purpose must be checked. To do this, the point of the indicator is brought close to a nearby live part. Disconnected equipment should be tested for no-voltage at all terminals, and each circuit breaker, at six terminals.

Temporary safety-earthing sets. Once a no-voltage test has been performed on the equipment on which installation

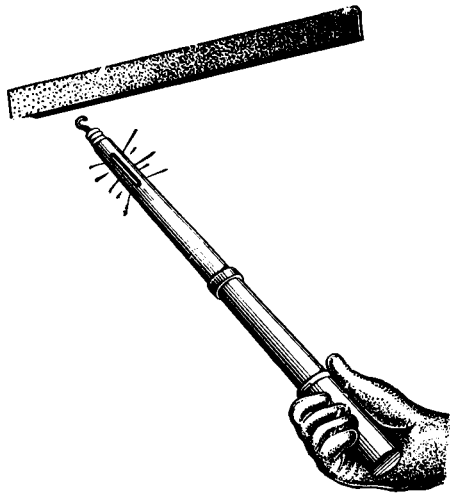


Fig. 192. Voltage indicator

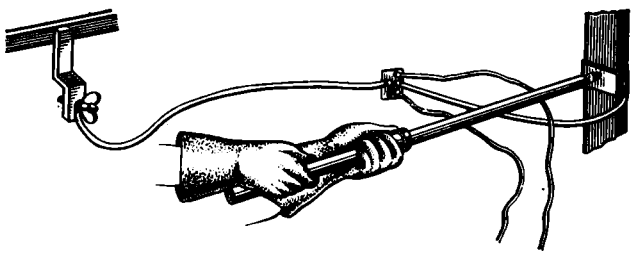


Fig. 193. Application of temporary safety-earthing set to current-carrying parts by means of insulating stick

or repair work is to be done, conductors are attached so that all three phases are returned to earth and shorted (Figs 193 and 194).

Temporary safety-earthing sets may be applied and removed only by two men working together, one of them with a safety rating not below Group IV, and the other, not below Group III. First an earthing set is connected to earth and then clamped, by means of an insulating stick, to the current-carrying parts of all three phases. These operations

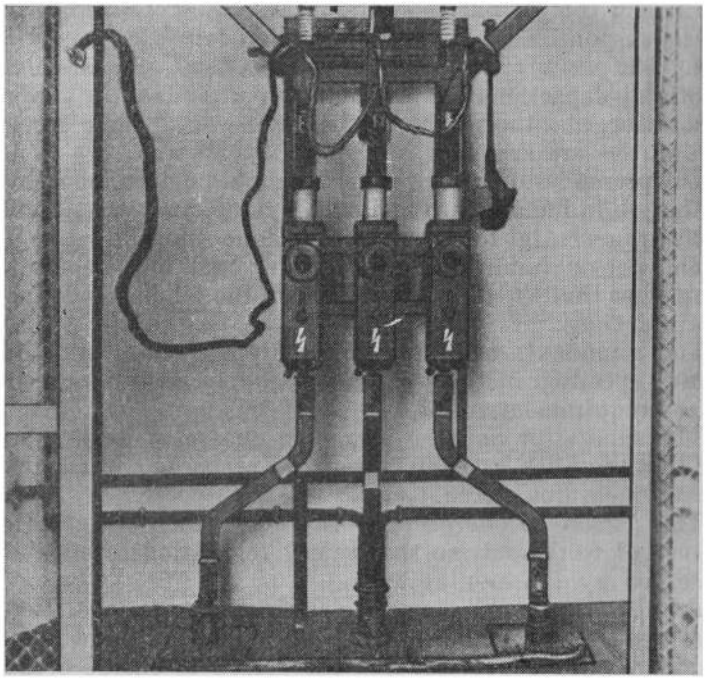


Fig. 194. Switchgear cell with safety-earthing set applied and circuit breaker prepared for maintenance work

should be performed with nonconducting gloves on. The power and instrument transformers must be disconnected in advance on the low-voltage side as well, as there exists the danger of reverse transformation of the low into a high voltage.

The organizational measures by which safety at work is ensured include: execution of work orders, permits to work on electrical installations, supervision during work, and signed clearances and cancellations.

Work orders. Work orders are written instructions for the performance of any work on electrical equipment. They fix the place, time, and conditions of work, the setup of

the crew, specific measures to be taken to ensure safety at work, and the persons in charge of safety.

The responsibility for safety is shared by the person issuing the work order (as a rule, the head of a station's electrical department or his deputy), attendant in charge, supervisor, and the person in charge of work. Their respective duties are specified below.

The person issuing the work order should determine whether the job in hand has to and can be done, and what conditions are essential for the job to be done safely.

The person issuing the work order and the supervisor should see that the men assigned to do the job have adequate qualifications.

The attendants on duty should prepare the work location as specified in the work order and in compliance with safety requirements.

The supervisor and the person in charge of work should see that the work location is properly prepared and adequate safety measures taken.

The person in charge of work should direct the performance of work and see that safety regulations are strictly observed by the men at work.

Admission of work crew to electrical installations. Before any work may commence, the attendant in charge accompanied by the supervisor and the person in charge of work first make sure once again that the necessary safety measures have been taken, and only then permit the crew to enter the switchgear premises. The attendant leads the way to the work location and touches the disconnected equipment for the whole crew to see that the current-carrying parts of the equipment have been de-energized. The crew is also shown the adjacent equipment left alive. All live parts should be fenced in.

During intervals and breaks in the course of a work-day, the entire crew must be escorted out of the switchgear building or switchyard, with the work order left in the hands of the person in charge of work. After the interval or break, the crew may be escorted to the work location by its leader in the absence of the operator.

Supervision during work on electrical installations. While work is being done on electrical equipment, the person in

Changes in Crew

Put on crew (names, initials, safety ratings)	Withdrawn from crew (names, initials, safety ratings)	Date and time	Permission given by (signature)

Daily Renewals of the Permit to Work, Completion of Work, Transfers to Other Jobs

Location of apparatus	Permit to work					Clearance
	Necessary safety measures taken. Crew acquainted with conditions for performance of work and with safety measures taken					Crew withdrawn. Work order turned in
	Remaining alive are ——— (state what current-carrying parts are left alive in the bus system repaired)					
	Date, time	Permission given by (signature)	Person in charge of work (signature)	Date, time	Person in charge of work (signature)	Operator in charge (signature)

The work covered by work order fully completed: ——— hour ——— min ——— day ——— month ——— year

Supervisor ——————————————————
(signature)

Apparatus and location accepted, work order turned in: ———

——— hour ——— min ——— day ——— month ——— year

Operator in charge ——————————————————
(signature)

Note. No cross-outs are permitted in a work order form. Enter in the operator's log all switchings performed and temporary safety-earthing sets applied (state their numbers).

Order Form for Work on Electrical Installations

Name of organization _____

WORK ORDER No. _____

To the person in charge, superintendent _____

_____
(name, initials, safety rating)

Job assigned _____
(specify installation, circuit, extent of work to be done)

Conditions of work _____
(with partial or full disconnection from service,

_____
on live equipment, with temporary safety-earthing, where and why)

Special instructions _____

Begin work at: ___ hour ___ min ___ day ___ month ___ year

Supervisor _____
(name, initials, safety rating)

Work order issued: ___ day ___ month ___ year by _____
(signature)

Crew setup _____ men _____

_____

_____
(names, initials, safety ratings)

Supervisor (or person issuing work order) _____
(signature)

Necessary safety measures taken ___ hour ___ min ___ day ___

_____ month _____ year

Operator in charge _____
(signature)

Safety of work in location/on apparatus checked: ___ hour ___

_____ min _____ day _____ month _____ year

Supervisor _____
(signature)

charge of work keeps constant watch over the men doing the job and sees that safety regulations are strictly observed by them. He must not leave the crew. If he has to go out of the switchgear premises, he must lead out the entire crew.

The working crew is also periodically overseen by the supervisor and the plant attendants on duty. If they see anyone of the crew breaking the rules of safety, the violator is ordered out of the switchgear premises. Those who are guilty of a gross negligence are punished.

Completion of work on electrical installations. At the end of the working hours, the work location should be made tidy. The work order should be handed over to the attendant on duty. The next day the crew may resume work after going through all the above formalities.

When all the repair work is completed, the work order is cancelled (signed) by the supervisor, and the work location and keys are taken over by the attendant in charge. After this, the equipment may be put back into operation.

77. Protective Aids Used in Electrical Installations

Protective aids are widely used where work is being done on electrical installations. They are employed in order to protect personnel against electric shock and arcs and to prevent the crew from approaching the current-carrying parts remaining alive.

The protective aids include:

portable voltage indicators and clip-on instruments;

temporary safety-earthing sets, portable guards, and warning notices;

protective goggles, canvas gloves, and gas masks for protection against arcs, fumes, and mechanical injury;

nonconducting gloves, boots, and rubbers, insulating pallets, rubber mats and blankets, insulating sticks, fuse pullers, and tools with insulated handles.

It is required that attended substations always have on hand a set of numbered temporary safety-earthing sets, assorted warning notices, portable temporary guards, and voltage indicators.

Unattended switchgear installations operating at over 1 000 V should be furnished with an insulating stick, in-

Testing Standards and Test Intervals for Protective Aids

Protective aids	Switchgear voltage	Initial and post-overhaul tests			In-service tests			Routine test intervals	Routine inspection intervals
		test voltage	test duration, min	leakage current, mA	test voltage	test duration, min	leakage current, mA		
Insulating sticks (other than measuring)	Under 110 kV	Three times line voltage, but at least 40 kV	5	—	Three times line voltage, but at least 40 kV	5	—	Every 2 years	Once a year
Measuring sticks	Under 110 kV	Three times line voltage	5	—	Three times line voltage	5	—	Every 3 months when used, but at least once a year	Once a year
Insulated tongs	1-35 kV	Three times line voltage, but at least 40 kV	5	—	Three times line voltage, but at least 40 kV	5	—	Every 2 years	Once a year
Insulated tongs	Up to 1000 V	3 kV	5	—	2 kV	5	—	Every 2 years	Once a year

Clip-on instruments	Up to 10 kV	Three times line voltage, but at least 40 kV	5	—	Three times line voltage, but at least 40 kV	5	—	Once a year	Every 6 months
Clip-on instruments	Up to 500 V	2 kV	5	—	2 kV	5	—	Once a year	Every 6 months
Voltage indicators insulated holder	Under 110 kV	Three times line voltage, but at least 40 kV	5	—	Three times line voltage, but at least 40 kV	5	—	Once a year	Every 6 months
Indicator proper with hook and capacitor lead	Up to 220 kV	20 kV	1	—	20 kV	1	—	Once a year	Every 6 months
Phasing tubes	2-6 kV	6 kV	1	1.7-2.4	6 kV	1	1.7-2.4	Once a year	Every 6 months
	10 kV	10 kV	1	1.4-1.7	10 kV	1	1.4-1.7	Once a year	Every 6 months
Active-current voltage indicators	Up to 500 V	1 kV	1	—	1 kV	1	—	Once a year	Before use
Tools with insulated handles	Up to 1000 V	2.5 kV	1	—	2 kV	1	—	Once a year	Before use

Table 23 (continued)

Protective aids	Switchgear voltage	Initial and post-overhaul tests			In-service tests			Routine test intervals	Routine inspection intervals
		test voltage	test duration, min	leakage current, mA	test voltage	test duration, min	leakage current, mA		
Nonconducting rubber gloves	Up to 1000 V	3.5 kV	1	3.5	2.5 kV	1	2.5	Every 6 months	Before use
Nonconducting rubber gloves	Over 1000 V	9 kV	1	9	6 kV	1	6	Every 6 months	Before use
Nonconducting rubber boots	Any	20 kV	2	10	15 kV	1	7.5	Every 3 years	Every 6 months
Nonconducting rubbers	Up to 1000 V	5 kV	2	2.5	3.5 kV	1	2	Once a year	Every 6 months
Nonconduct-	Up to 1000 V	5 kV	Pulling	5	—	—	—	—	Once a

ing rubber mats			at 2-3 cm/s through cylindrical electrodes						year
Nonconducting rubber mats	Over 1000 V	20 kV	Same	20	—	—	—	—	Once a year
Insulating pallets	Up to 10 kV	40 kV	1	—	—	—	—	—	Every 2 years
Insulating plates:									
rigid	Up to 10 kV	20 kV	5	—	20 kV	5	—	Every 2 years	Once a year
rubber	Up to 1000 V	5 kV	1	5	3.5 kV	1	3.5 kV	Every 3 years	Once a year
Nonconducting rubber caps	Up to 10 kV	10 kV	2	—	10 kV	1	—	Every 3 years	Once a year

sulating pallet (or rubber boots), and fuse pullers. The other protective aids, such as rubber gloves, voltage indicators, goggles, warning notices, portable guards, shorting and earthing jumpers, and gas masks, should be kept by the crews servicing the electrical installations and brought by them to the work location.

The protective aids assigned to a given substation should be kept in a suitable room or place.

All protective aids should be tested before use for the first time and then at the intervals specified in Table 23. A protective aid should also be tested each time some of its parts have been replaced or when there is doubt as to its fitness. Protective aids, both in use and in storage, are tested at the same intervals. Protective aids are inspected for condition and missing items every three months. Protective aids are subjected to a high-voltage test by a properly trained person on a suitable test unit.

Before use, a protective aid should be checked for overall condition, external damage, and dirt on its surfaces. It is not permissible to use insulating sticks and fuse pullers which are covered with dust and bear traces of carbon and pencil marks. Rubber gloves, boots, and rubbers should be free from fins, cracks, blisters, etc. Defective protective aids should be immediately taken out of service.

Before protective aids may be used, they should be checked for the date of next test stamped on them, to make sure that it is not overdue. If it is, such aids must not be used. Furthermore, with insulating sticks, fuse pullers, and voltage indicators, their stamped marks should be checked to see for what voltage they may be employed.

78. First Aid Given to Victims of Electric Shock

According to safety regulations, personnel operating and servicing electrical installations should be regularly instructed on the hazards of electric current and methods of first aid, trained in breaking a shock victim's contact with the source of current and in the application of artificial respiration.

Efficient first aid to a victim of electric shock greatly depends upon fast action, resourcefullness, and the skill

to render it. This skill is acquired through practical exercises.

If a victim is still in contact with live equipment, the very first thing to do is to de-energize this equipment.

To break the victim's contact with live parts at voltages up to 1 000 V, dry clothing, a dry rope, board, or any other dry non-conductor must be used.

When freeing a victim from contact with live equipment at above 1 000 V, the following must be borne in mind:

if the victim is aloft, measures must be taken to prevent him from falling or to make his fall safe;

if the victim is in contact with one conductor, it is often sufficient to earth only this conductor;

the wire used to short or earth the conductor must first be connected to earth and then thrown across the line conductors to be earthed;

if it has a high capacitance, an opened line may retain a charge dangerous to life, and only reliable earthing will make it safe.

On breaking the victim's contact with the source of current, he must be given first aid without delay, and a doctor must be called. If the victim does not breathe, artificial respiration should be applied at once.

All personnel operating and servicing electrical equipment must be trained in the application of artificial respiration as described in guides and instructions on the subject.

Questions

1. What general safety requirements must be complied with in operating and maintaining electrical installations?
2. What requirements are placed on technical measures taken to ensure safety at work on electrical installations?
3. What requirements are placed on organizational measures taken to ensure safety at work on electrical installations?
4. What protective aids are used in doing work on electrical installations?
5. What requirements are imposed by safety regulations on the testing standards and test intervals for protective aids?

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